The EMPIRE JOURNAL of EXPERIMENTAL AGRICULTURE

VOLUME XXIII

OXFORD
AT THE CLARENDON PRESS
LONDON: GEOFFREY CUMBERLEGE
1955

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THE USE OF CYTOPLASMIC MALE STERILITY IN THE PRODUCTION OF HYBRID MAIZE SEED

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WITH PLATE I

SUCCESSFUL production of double-cross hybrid maize seed involves the planned crossing of four inbreds or pure lines. The first step is to cross the inbreds in pairs, and secondly to combine the resultant two single crosses. The accepted procedure for producing double hybrid seed in the field is to plant an isolated field with the two single crosses, in alternating strips of predetermined row proportions, and to remove by hand the tassels from the single cross used as seed parent in order to ensure pollination by the male single-cross parent. This detasselling of the seed-parent rows is a painstaking operation and has always been considered one of the most expensive and hazardous items in the production of maize hybrids. In a country with cheap labour the expense of detasselling may not be considered a decisive factor but it is still a consideration. A major hazard experienced when the plants are growing rapidly is that producers are sometimes unable to remove the tassels before they shed pollen, and this is particularly true when the removal of tassels is suspended over week-ends. Any method of obviating detasselling would reduce the cost of seed production considerably and would also eliminate the necessity for rejecting seed-production fields that have not been properly detasselled.

The most promising method yet suggested to eliminate detasselling is through the utilization of cytoplasmic male-sterile inbreds. The author became interested in this method while at the Kentucky Agricultural Experiment Station and has continued and expanded the study at the Potchefstroom College of Agriculture and Experiment Station. The present paper reports the results of this investigation.

General procedure.—The origin of cytoplasmic male sterility, and previous studies on its behaviour, have been adequately reviewed by Rogers and Edwardson [1]. The general procedure employed in the use of cytoplasmic male-sterile inbreds to produce maize hybrids is described by these authors and by Jones and Everett [2]. In brief, the method consists of transferring the cytoplasmic male-sterile character to that inbred line which is to be the maternal parent of the single-cross seed parent used in making the double cross. This inbred line must be one in which the male-sterile character remains stable. In the production of the seed-parent single cross it is not necessary to remove the tassels from the maternal inbred since it produces no pollen. Likewise in producing the double cross it is not necessary to remove the tassels from the seed-parent single cross since it remains sterile. Obviously

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[Empire Journ. of Exper. Agric., Vol. 23, No. 89, 1955]

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this double-cross seed cannot be grown as such by farmers since there would be no pollen produced to effect fertilization and cause the seed to set. In order to ensure ample pollen for the final grain crop, it would be necessary to mix seed produced from normal single crosses with that produced from male-sterile single crosses. The procedure for such a method is described by Hofmeyr [3]. Another possible method is to develop a single-cross pollinator which is capable of restoring fertility when crossed on to the male-sterile single cross. It is this latter method only which has been considered for the practical production of male-sterile hybrids in the present work.

Materials and Methods

Two sources of the cytoplasmic male-sterile character were used in these studies. One source, having its origin in the variety Golden June and transferred to the inbred Tx61M, was received from Dr. John S. Rogers of the Texas Agricultural Experiment Station. This source, Tx61Mms, has been very stable and it was the one used most extensively in the present work. The other source resulted from continuous backcrossing with inbred Ky27, following the initial cross to inbred 33–16 as the seed parent, done in an effort to determine the causes for poor seed set in certain double-cross hybrids in which 33–16 was used as the maternal parent of the seed-parent single cross [4]. This male-sterile inbred is designated Ky27ms. It is identical with Ky27 except for the male-sterile character, and as it is very poorly adapted under the conditions obtaining at Potchefstroom it has not been considered in the bulk production of male-sterile double-cross hybrids.

The behaviour of the male-sterile character from both sources was studied in several crosses at the Kentucky Agricultural Experiment Station in 1952, and at Potchefstroom in 1952–3. The more promising locally developed white and yellow inbreds were crossed on Tx61Mms and tested in 1953–4 in order to determine the influence of genes carried by different inbreds on the cytoplasmic male-sterile character, and also to transfer this character to the more important inbreds. All crosses were examined at flowering for their degree of sterility and the plants were classified as completely sterile, shedding anthers but with no pollen, partially sterile, and normal. All plants falling in the two intermediate classes were examined in iodide solution under a low power microscope for the percentage of viable pollen grains. The proportion of normal-appearing pollen grains in partially sterile tassels ranged from about 20 to about 80 per cent., and those in which the anthers emerged but had no viable pollen were considered as completely sterile. Illustrations of sterile and normal tassels are shown in Fig. 1 (Plate 1). Sterile tassels have a sparse, slender, and flattened appearance, while normal tassels are more condensed and the spikelets are well filled. The anthers which emerged from sterile tassels that produced no viable pollen were characteristically small, dry, and hard (Fig. 2).

The test crosses of inbreds on Tx61Mms showed that several inbreds apparently lacked the genes necessary to produce sterility when in

combination with the male-sterile cytoplasm, and they would, therefore, restore fertility. Double crosses combining these inbreds in the single-cross pollinator, and using 33–16, Ky39, Ky211, and K44 as pollinators on Tx61Mms as the single-cross seed parent, were yield-tested at Potchefstroom in 1953–4. Comparable fertile and sterile single crosses were also grown to determine the effect of the male-sterile character on yield.

It was suggested by Josephson and Jenkins [4] that it should be possible, through back-crossing, to develop a strain of 33–16 that does not carry the cytoplasmic contribution to male sterility which it has been demonstrated to possess normally. Back-crosses have been made to 33–16, following the initial crosses to K64 and CI.43 as female parents. Test crosses for degree of sterility in comparison with original 33–16 were made following the fourth back-cross and were tested at Potchefstroom in 1952–3. Crosses for yield comparisons with original 33–16 were made following the sixth back-cross and were tested in the trial of male-sterile double crosses.

Experimental Results

Results of male-sterile character in single crosses.—The results obtained in the 1952–3 tests are presented in Table 1. The male-sterile determinants in Tx61Mms and Ky27ms were stable, and both lines remained sterile provided they were pollinated by their fertile counterparts. The male-sterile cytoplasm might be expected to remain unaffected in each, in the presence of the genotype contributed by the inbreds Tx61M and Ky27 respectively. The results presented in Table 1 show how the genotypes of other inbreds affected the male-sterile character from these two sources, and also indicate the inbreds that can be used in the production of male-sterile hybrids. The behaviour of the lines was the same in this trial as in that conducted at the Kentucky Agricultural Experiment Station and some other states [5], with four exceptions. These exceptions occurred with those lines in which the anthers emerged but produced no pollen or produced some proportion of partially sterile tassels, so that these discrepancies could as well have been due to uncertainty in classifying the tassels as to the effect of different environments.

The results showed that fifty-two of the sixty-one inbreds tested against the male-sterile character in Tx61M carried chromogenes[1] [6] that did not affect the cytoplasmic factor and were therefore similar to this inbred in their effect on the character. All these inbreds are assumed to possess the same set of such chromogenes in their genotype, although thirteen of the fifty-two inbreds classified as sterile produced some proportion of tassels in which anthers emerged but contained no viable pollen. On the other hand, the inbreds K55, Ky122, Ky21, R6, R7, and K6 restored fertility completely when crossed with this male-sterile line, and they are assumed to be homozygous for such restorer genes. The cross with K63 had one partially sterile tassel in the popula-

[1] Terminology suggested by D. F. Jones for inherited determiners carried in the chromosomes, as opposed to plasmagenes which are carried entirely in the cytoplasm.

TABLE 1. *Reaction of Inbred Lines on the Degree of Male Sterility, in Single Crosses with Standard Sources, Potchefstroom, 1952–3*

(Classification of plants in per cent.)

Source	*Tx61Mms*				*Ky27ms*			
	Sterility				*Sterility*			
Inbred line†	*Complete*	*A.e.n.p.**	*Partial*	*Fertile*	*Complete*	*A.e.n.p.**	*Partial*	*Fertile*
Mo2RF	..	..	..	..	35	65	0	0
Ky27	78	22	0	0	100	0	0	0
Ky39	100	0	0	0	0	0	0	100
Ky39×Ky21	67	6	0	27	0	0	0	100
K55	0	0	0	100	84	16	0	0
K63	0	0	6	94	83	17	0	0
H21	100	0	0	0	0	0	100	0
CI.61	100	0	0	0	0	80	13	7
Ky209	100	0	0	0	0	0	100	0
Ky211	100	0	0	0	75	25	0	0
33–16	100	0	0	0	24	35	41	0
WF9	100	0	0	0	95	5	0	0
Ky36–11	79	21	0	0	6	94	0	0
Ky106	100	0	0	0	50	50	0	0

Source	*Tx61Mms*			
	Sterility			
Inbred line	*Complete*	*A.e.n.p.**	*Partial*	*Fertile*
K64	0	0	100	0
Ky122	0	0	0	100
Ky21	0	0	0	100
Ky39–24	94	6	0	0
R6	0	0	0	100
R7	0	0	0	100
R27	47	53	0	0
K6	0	0	0	100
K60	68	32	0	0

Source	*Tx61Mms*			
	Sterility			
Inbred line	*Complete*	*A.e.n.p.**	*Partial*	*Fertile*
Ky205	28	72	0	0
Ky207	82	18	0	0
Ky213	37	63	0	0
CI.7	89	11	0	0
T202	0	0	37	63
38–11	94	6	0	0
K148	78	22	0	0
L304A	79	21	0	0
Ky42–86	58	42	0	0

*Anthers emerged, no pollen.

†In addition to those appearing in the Table, the following inbred lines showed complete sterility (classification 100-0-0-0) when crossed with Tx61Mms: Ky49, Ky89, Ky114, Ky124, Ky201, R24, CI.23, K41, K44, H22, H23, Ky41, Kys, R32, B18, CI.27, Oh07, K155, Ky35–7, Ky35–61, Ky36–24, R33, R36, R38, CI.21E, T8, K150, Oh28, Ky126, Ky43–38, and Ky120.

tion, so new seed was produced and tested in 1953–4. As all these plants were completely fertile, the one partially sterile plant in 1952–3 is considered to have originated from an admixture of pollen and the inbred is placed with those restoring complete fertility.

The inbred T202 produced more than 50 per cent. fertile tassels and was probably heterozygous in respect of the chromogenes necessary for restoring fertility, while K64 apparently lacked some of those necessary since all the tassels of the cross were only partially fertile. Back-crosses of K64 to these partially fertile plants produced sterile and fertile plants in equal proportion, indicating that it should be possible to develop sub-lines capable of restoring fertility and also others capable of maintaining sterility. The stability of inbreds in maintaining sterility, and the influence of back-crossing, are illustrated by the fact that the F_1 of K41 on Tx61Mms grown in 1952–3 was completely sterile while the BC_1 generation grown in 1953–4 showed 50 per cent. of the plants to be only partially sterile. In a more extreme instance, the BC_1 generation of Ky209 on Tx61Mms was completely fertile whereas the F_1 grown in 1952–3 was sterile. The two generations will be grown again to determine the possible effects of environment and of errors in making the pollinations.

Variability in the effects of the inbreds on the two sources of cytoplasmic male sterility is indicated in Table 1. The fact that nine of the thirteen lines tested on Ky27ms had emerged anthers, but produced no pollen, while all of these nine, except one, tested on Tx61Mms were completely sterile would indicate that the male-sterile character in Ky27 was not completely stable. On the other hand, K55 and K63 restored fertility when crossed with Tx61Mms but not when crossed with Ky27ms, which would indicate that the male-sterile determinants in the two sources were different. The restoration of fertility by Ky39 on Ky27ms but not on Tx61Mms would confirm this. These crosses were grown again in 1953–4 with similar results. The results presented by Josephson and Jenkins [4], for Mo2RF, K63, H21, and Ky39 crossed on 33–16 as the seed parent, were similar to those presented here for Ky27ms. Their results also showed that Ky49 produced no sterility with the cytoplasmic male-sterile character in 33–16 whereas it was completely sterile with Tx61Mms, and K6 with 33–16 was partially sterile, whereas it restored fertility with Tx61Mms. On the other hand, no sterility was exhibited in either case with Ky21 and Ky122. These comparisons indicate that the male-sterile determinants in the two sources were undoubtedly different.

Ky27ms has the cytoplasm of 33–16, an inbred line which is completely fertile in itself. In crosses that have this line as seed parent, male sterility depends on having the appropriate inbreds as pollinator parents. Apparently 33–16 contains pollen-restoring chromogenes or a genetic make-up which is able to overcome the effect of the cytoplasm controlling sterility. Since Ky27ms was developed by successive back-crosses to Ky27 following the initial cross to 33–16 as seed parent, the chromogenes of 33–16 have been replaced by those of Ky27, which renders this source of sterility fairly stable. This is supported by the

fact that 33–16 crossed on this source rendered 41 per cent. of the plants partially fertile. Since the majority of crosses produced some proportion of sterile plants in which anthers emerged, it would appear that complete sterility is dependent on the inbreds having a chromogenic make-

TABLE 2. *Performance of Male-sterile and Fertile Hybrids Grown at Potchefstroom, 1953–4*

Hybrid pedigree	*Yield per morgen**		*Classification of plants*		*Plants erect at harvest*
	Bags (200 lb.)	*% of mean yield*	*Fertile*	*Sterile*	
			%	%	%
(Tx61Mms. × 33–16) × (K55 × Ky21)	37·2	112·4	100·0	0·0	55·0
,, × (K55 × K64)	32·8	99·1	52·2	47·8	85·0
,, × (K55 × Ky122)	37·1	112·1	100·0	0·0	81·0
,, × (K55 × R6)	25·7	77·6	100·0	0·0	82·7
(Tx61Mms × Ky39) × (K55 × Ky21)	29·4	88·8	100·0	0·0	69·2
,, × (K55 × K64)	31·0	93·6	60·9	39·1	87·0
,, × (K55 × Ky122)	31·1	94·0	100·0	0·0	52·8
,, × (K55 × R6)	30·2	91·2	100·0	0·0	86·1
(Tx61Mms × Ky211) × (K55 × Ky21)	28·8	87·0	100·0	0·0	70·7
,, × (K55 × K64)	33·0	99·7	73·3	26·7	90·0
,, × (K55 × Ky122)	31·1	94·0	100·0	0·0	67·4
,, × (K55 × R6)	30·0	90·6	100·0	0·0	74·4
(Tx61Mms × K44) × (K55 × Ky21)	34·6	104·5	100·0	0·0	48·7
,, × (K55 × K64)	36·2	109·4	61·4	38·6	75·3
,, × (K55 × Ky122)	32·8	99·1	100·0	0·0	55·1
,, × (K55 × R6)	31·3	94·6	100·0	0·0	72·0
Hybrid P.P. × K64	39·3	118·7	97·7	2·3	84·4
P3141c(N72 × K64) × (33–16 × K55)	35·4	106·9	100·0	0·0	61·2
P4116A(A17 × A14) × (N72 × K64)	42·8	129·3	100·0	0·0	93·7
Mean of entries	33·1	100·0			
L.S.D., P = 0·05	4·5	13·6			

* morgen = 2·1165 acres.

up similar to Ky27. On this basis Ky39, which restored complete fertility to Ky27ms, must be identical with 33–16 in respect of all chromogenes controlling sterility.

Thirteen additional white dent lines and thirteen yellow dent lines were crossed to Tx61Mms, and tested and back-crossed in 1953–4. A14 and E184 in the whites and A447 and C474 in the yellows restored complete fertility, while A415 was heterozygous in this respect.[1] In addition to the white lines K55, K64, Ky211, 33–16, K41, and K44 previously converted to one or both sources of sterility, the lines A13, A15, A16, A17, A20, A21, A22, N75, N72, K61, and N52 were back-crossed to transfer the cytoplasmic male-sterile character. In the yellows A435, A436, A437, A441–2B, A446–1B, A463–3B, A468, C430, C432,

[1] All A-, C-, and E-numbered inbreds were developed at Potchefstroom while all other inbreds reported in this paper were developed in the United States.

and C438 are being converted, in addition to WF9, Ky36–11, Ky106, KYS, and T8 previously converted.

The segregation obtained with the single-cross Ky39 × Ky21 on Tx61Mms, in comparison with the two inbreds, indicates the chromogenic action on male-sterile cytoplasm and the need for fertility-restoring chromogenes to be present in both inbreds of the pollen-parent single cross if all plants of the final cross are to be fertile.

TABLE 3. *The Degree of Male Sterility in Crosses with Ky27ms, 33–16, and Recovered 33–16 Lines, Potchefstroom, 1952–3*

*Inbred seed parent**	*Inbred or single-cross pollen parent*	*Classification of plants in per cent. Sterility*			
		Complete	*Anthers emerged, no pollen*	*Partial*	*Fertile*
33–16.Ky27^{3}ms	K63	83	17	0	0
33–16		0	22	29	49
K64.33–16^4†		0	0	0	100
CI.43.33–16^4†		0	0	0	100
33–16.Ky27^{3}ms	MO2RF	35	65	0	0
33–16		0	27	73	0
K64.33–16^4		0	0	0	100
CI. 43.33–16^4		0	0	0	100
33–16.Ky27^{3}ms	Ky27 × CI.61	82	18	0	0
33–16		17	33	29	21
K64.33–16^4		0	0	0	100
CI.43.33–16^4		0	0	0	100
33–16.Ky27^{3}ms	CI.43 × CI.61	20	80	0	0
33–16		0	11	16	73
K64.33–16^4		0	0	0	100
CI.43.33–16^4		0	0	0	100

* The superscript number following the inbred line indicates the number of back-crosses to that inbred following the initial cross to the first-named inbred.

† The data represent the results of crosses to 2–4 selections.

Yields of male-sterile double crosses.—A yield trial of sixteen male-sterile double crosses compared with hybrid P.P. × K64 and two experimental double-cross hybrids was conducted at Potchefstroom in 1953–4. The four single crosses K55 × Ky21, K55 × K64, K55 × Ky122, and K55 × R6 were used as pollinators, on male-sterile single crosses that had 33–16, Ky39, Ky211, and K44 as male parents on to Tx61Mms. A randomized block design with four replications was used. The results are presented in Table 2. Pollen fertility was completely restored in all hybrids except those having K64 in the pollinator parent, showing that both inbreds in the male parent must restore complete fertility in order that all plants of the double cross should be completely fertile. The hybrids with K55 × Ky21 and K55 × Ky122 as pollen parents on Tx61Mms × 33–16, and K55 × K64 on Tx61Mms × K44, were not significantly lower yielding than the commercial hybrid P.P. × K64 and may be suitable for bulk production. All inbreds involved

in the crosses were fairly well adapted at Potchefstroom and the crosses were suited to production as far as flowering time was concerned.

Seed of comparable fertile and sterile single crosses made in a greenhouse produced such poor stands that comparisons of yield could not be obtained.

Test crosses with recovered 33–16 lines.—The results of the test crosses of inbreds and single crosses to 33–16.Ky27[3]ms, (Ky27ms), 33–16, and the recovered 33–16 lines, are given in Table 3. All crosses with the recovered 33–16 lines were completely fertile, which shows that the male-sterile cytoplasm has been completely eliminated from this inbred.

The yield and agronomic results from various crosses, comparing original 33–16 with the recovered strains, were influenced by variability in stands and different sources of seed used as male parents, so the detailed figures are not presented. The crosses with the recoveries, however, appeared identical with those with the original 33–16, except that the strain recovered through CI.43 was slightly later in flowering in all instances than the one recovered through K64 and the original 33–16. The original 33–16 and the recovered strains were likewise identical in appearance and yield.

Eight back-crosses to 33–16 have now been made and additional crosses are being produced for a more critical comparison of the recovered strains with original 33–16.

Discussion

The information so far obtained indicates that the utilization of the male-sterile character in inbreds, to obviate detasselling in the production of maize hybrids, has definite possibilities. The male-sterile character can be transferred by back-crossing to any inbred line provided that the line does not affect this character. Male-sterile inbreds must be propagated by pollinating with their fertile counterparts, either by hand pollination or in a crossing block where the fertile counterpart is used as pollinator.

Several inbreds have been found that are capable of restoring fertility when crossed with male-sterile progenies, and hybrids involving these inbreds have been produced and tested. In the commercial production of these hybrids it is not necessary to remove the tassels from the maternal inbred in producing the seed-parent single cross, since it forms no pollen. Likewise, it is not necessary to detassel the seed-parent single cross in producing the double cross since it is also completely pollen sterile. It is essential, however, that the male-parent inbred of this seed-parent single cross be incapable of restoring fertility in the cross. The final double cross which the farmer would grow is completely fertile, since inbreds are used in the single-cross pollinator that restore complete fertility to the hybrids. It is desirable, but not necessary, that both inbreds in the pollen parent should restore complete fertility. It was shown that in the hybrids with K55 × K64 as the pollen parent, where only K55 restores complete fertility, sufficient

pollen is produced to give a good seed set in the final hybrid. Three of the sixteen hybrids tested were not significantly lower yielding than hybrid P.P. × K64 and may have possibilities for commercial production. In the meantime the male-sterile character is being transferred to all the promising white and yellow inbreds and this will allow a wider range of hybrids to be produced. The transfer of the fertility-restoring chromogenes to other inbreds has also been started.

The various test crosses and studies with the male-sterile character have offered some interesting possibilities producing and utilizing this character. It was shown that inbreds which have no effect on male-sterile cytoplasm and those which completely restore fertility are fairly stable. Those inbreds which are heterozygous, however, appear to be greatly influenced by environment, and it will be necessary to test them under a wide range of conditions before using them in the production of hybrids. Test crosses showed that the two sources of sterility used in these studies were different. The chromogenes in K55 and K63 restored fertility in Tx61Mms but had no effect on Ky27ms. On the other hand, Ky39 restored fertility in Ky27ms but not in Tx61Mms. Test crosses of other inbreds that restore fertility when crossed with Tx61Mms are being crossed to Ky27ms to determine their effect on this source of cytoplasm. It is suspected that Ky21 will also restore fertility in the Ky27ms source, since the single cross Ky39 × Ky21 restores complete fertility in the cross. It will be necessary, therefore, to test all inbreds to the particular source of cytoplasm with which they are to be used.

The origin of Ky27ms is of particular interest since 33–16 in itself is completely fertile. Apparently 33–16 has fertility-restoring chromogenes specific to its own cytoplasm. The male-sterile character becomes apparent only when the chromogenes are replaced by their supposedly amorphic alleles. This is evidenced by the fact that when 33–16 was crossed to this source of sterility some of the plants were partially fertile. It is expected that further back-crosses with 33–16 to replace the chromogenes of Ky27 will again render this source completely fertile. It also suggests the possibility that other inbreds may carry male-sterile cytoplasm, but the expression of sterility is inhibited by restorer genes. Sterility in such inbreds will only become apparent when their chromogenes are replaced by those having no effect on that type of cytoplasm. A number of sterile segregates have been obtained in the course of self-pollinating open-pollinated varieties, in the breeding programme at Potchefstroom. These segregates are being studied further with the object of finding additional sources of the male-sterile character.

In the process of transferring the male-sterile character to inbreds K64 and K41, it was observed that some of the back-cross progeny reverted to fertility. This offers the possibility, as suggested by Rogers and Edwardson, of developing sub-lines from them capable of either restoring fertility or maintaining sterility. However, if they are heterozygous for the chromogenes affecting the male-sterile character, continued back-crossing to these lines would normally maintain their

male-sterile heterozygosity, and it would be impossible to select sub-lines homozygous for sterility. Sub-lines homozygous for fertility-restoring chromogenes can be obtained, after the required number of back-crosses, by selfing and selection. These sub-lines would necessarily contain the male-sterile cytoplasm from the original cross, but this should be no objection if they are used only as fertility restorers in male-sterile hybrids. Lines selected for complete sterility would have to be pollinated by the heterozygous inbred in order to maintain them. The possibility of selecting the two types of sub-lines within the same inbreds seems quite remote.

Inbred 33–16 has proved to be a valuable addition to the maize programme in South Africa. Its use is limited, however, because of the possibility of male sterility when it is used as the maternal parent in making the seed-parent single cross. Recovered strains have been obtained by back-crossing following initial crosses to K64 and CI.43 as seed parents. Test crosses have shown that the male-sterile cytoplasm has been completely eliminated from these recoveries and that they are practically identical with original 33–16. Eight back-crosses have now been made and additional comparisons will be conducted before a recovered strain is substituted for the original inbred line in the production of hybrids.

Summary

The commercial production of hybrid maize seed can be made easier if detasselling is eliminated by the use of cytoplasmic male-sterile hybrids. Studies on the utilization of such hybrids in South Africa are described.

Two sources of the male-sterile character were used, and their behaviour in numerous crosses and back-crosses was examined. A number of inbred lines were found which restored fertility when crossed with male-sterile progenies, and which could thus be used for the commercial production of male-sterile hybrids. Work with these and other inbred lines is continuing, and the inheritance of fertility and sterility is being further investigated.

Acknowledgement.—The author is indebted to Mr. J. F. Shane of the Kentucky Agricultural Experiment Station, who obtained the results from crosses with both male-sterile sources in 1952, and who produced the seed for the male-sterile double crosses tested at Potchefstroom in 1953–4.

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(*Received 20 October 1954*)

FIG. 1. Tassel from male-sterile plant (left) and normal plant (right)

FIG. 2. Anthers from male-sterile plants (left) and from normal pollen-shedding plants (right)

LEAF ANALYSIS AS A GUIDE TO THE NUTRITION OF BANANAS

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THE analysis of the leaves of plants as a guide to their nutritional requirements is being used to great advantage in the field of agricultural chemistry. Goodall and Gregory [1] have reviewed the methods used and have set out the levels of nutrient elements in different parts of many plants which may be related to the performance of the plant in the field. Most of this work, however, was done on temperate and sub-tropical crops, and no published work exists on the use of this technique as a guide to the nutritional status of the banana plant.

After sugar cane, bananas are the second most important crop of Jamaica, and the island's economy has always been closely linked to banana production. The record of 29 million banana stems exported from the island in 1939 was, however, followed in the years of World War II by a steady decline of production, due to the ravages of 'Panama disease' and to the degradation of land as a result of soil erosion brought about mainly by the poor management of banana plantations.

It is an established fact that soil conservation and the use of fertilizers are the only means of bringing worn-out lands back to a reasonable level of productivity. The primary aim of the work reported here was, therefore, to investigate the use of leaf analysis as an aid to soil tests in determining the need for fertilizers to be used on banana plantations.

The banana is botanically very dissimilar to most orchard crops, and Chandler [2] describes the plant as follows: 'Although the banana may be 10–30 ft. tall it is really not a tree but a great perennial herb. What appears to be a stem is composed of compressed leaf stalk bases arranged spirally in strips. The outer sections are of the older, lower leaves. Successive new leaves grow up in the centre and as they expand press the older bases outward. The rhizome is the true stem of the banana plant. After the last leaf has pushed up from the rhizome an inflorescence begins to grow up in the centre of the cylinder of compressed curved leaf stalks. The time between planting of the rhizome or sucker and beginning of flower initiation may be six to eight months; another month or more is then required for the inflorescence to reach the top. After emerging at the top the inflorescence turns downward so that the base of the flower cluster axis is upward.'

Preliminary Investigations on Sampling

The leaves of the banana plant are the site of major chemical activity during the plant's life, and the analysis of this part of the plant appeared to be the most likely indicator of its nutritional status.

It was decided first to investigate the differences that exist between the

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various leaves of mature plants in order to decide which leaf would be the truest indicator of the plant's nutrition. As shown above, the newest leaves all grow up out of the centre of the plant, and it is thus relatively simple to number the leaves in succession downwards, taking the latest fully opened leaf as the first leaf in the succession.

TABLE 1. *Total Nitrogen in Successive Banana Leaves (per cent.)*

Leaf No.	*Sites*						
	1	*2*	*3*	*4*	*5*	*6*	*Mean*
1st leaf . .	3·16	2·93	3·20	2·47	2·29	2·91	2·83
3rd ,, . .	3·53	2·96	3·78	2·63	2·61	3·23	3·21
5th ,, . .	3·44	2·83	3·43	2·76	2·54	3·21	3·09
7th ,, . .	3·07	2·71	..	2·32	2·43	..	2·63

Six sites were selected in various sections of the island, and the first, third, fifth, and seventh leaves were sampled from twenty-four plants on each site. The leaves were cut from the plants, and sections in the centre of the leaf lamina were removed, transported to the laboratory, and analysed.

TABLE 2. *Phosphate and Potash in Successive Banana Leaves*

(*a*) *Phosphate* (*per cent.* P_2O_5)

Leaf No.	*Sites*						
	1	*2*	*3*	*4*	*5*	*6*	*Mean*
1st leaf . .	0·71	0·69	0·81	0·67	0·59	0·61	0·68
3rd ,, . .	0·63	0·54	0·69	0·57	0·56	0·52	0·59
5th ,, . .	0·59	0·53	0·56	0·54	0·67	0·46	0·56
7th ,, . .	0·59	0·60	..	0·52	0·54	..	0·56

(*b*) *Potash* (*per cent.* K_2O)

Leaf No.	*Sites*						
	1	*2*	*3*	*4*	*5*	*6*	*Mean*
1st leaf . .	4·49	4·45	2·85	5·55	4·30	5·28	4·49
3rd ,, . .	4·08	4·00	2·68	3·45	4·57	5·17	3·98
5th ,, . .	3·96	4·99	2·04	3·72	4·00	5·02	3·62
7th ,, . .	3·99	4·25	..	3·48	3·14	..	3·72

The results of the determination of nitrogen content are presented in Table 1. (Results in this and succeeding tables are on a dry-matter basis.)

On almost all sites the third leaf showed a consistently higher content of total nitrogen than did any other leaves. There was also a consistent decrease in the nitrogen content for successively older leaves.

The phosphorus and potassium results are set out in Table 2.

It was found that the contents of phosphorus and potassium bore a direct relation to the age of the leaf, and there were consistently lower amounts of these elements in successive leaves from the same plants.

The results presented in Table 1 and 2 suggest that the third leaf gives the most general indication of the nutrition of the tree, and it was decided that samples from the third leaf should be used in all future work.

This preliminary investigation also gave useful information on the range of values which could be expected. Sites included areas which were known to suffer from a deficiency in the soil of one or more of the three major plant nutrient elements. The range of values found was: Nitrogen, 2·3–3·8 per cent. N; Phosphate 0·53–0·81 per cent. P_2O_5; Potash 2·0–5·3 per cent. K_2O.

TABLE 3. *Analyses of Leaves Taken at Two Stages in the Life of Mature Trees*

	Total nitrogen (*per cent.* N)		*Phosphate* (*per cent.* P_2O_5)		*Potash* (*per cent.* K_2O)	
Stage	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)
Grove Farm . . .	2·34	2·31	0·48	0·36	3·36	2·97
Glastonbury . . .	2·62	2·50	0·33	0·33	3·01	2·84
Mean . . .	2·52	2·40	0·40	0·34	3·18	2·90

The second investigation on sampling was undertaken to determine the best time in the life of the trees for taking the samples.

Some attempts were made to determine the time when the inflorescence started to grow up from the rhizome. The only means by which this could be determined would be to push a sharp instrument such as a thin knife through the soft tissue and to feel the hard stem coming up through the interior of the plant. All attempts to work out a suitable technique for this proved ineffective, and it was decided that no comparisons could be made before the inflorescence had emerged or, as it is commonly termed, before the plants had 'shot'.

Leaves were therefore taken from bananas at two stages in order to determine the most opportune time for sampling: (*a*) as soon as possible after the appearance of the inflorescence; (*b*) at the time of maturity of the fruit, some three months after (*a*). The results of analysis are presented in Table 3.

The leaves taken at the time of shooting, (*a*), generally had a higher content of the nutrient elements and this stage was therefore selected for the time of sampling.

Investigations in Determining the Critical Levels

At the same time that these preliminary investigations in the leaf-analysis technique were started, three $3 \times 3 \times 3$ fertilizer experiments were put down to determine the effects of NPK fertilizers on the yield

of the Lacatan banana. These experiments had been sited on soil types found in important banana-growing areas of the island, and it was therefore decided to take leaf samples from the plots of experiments in an attempt to determine, (*a*) the minimum levels of the concentration of the elements in the leaves which could be related to high banana yields; (*b*) the relation between leaf analyses and fertilizer responses or nutrient status.

Methods of sampling and analysis.—The third leaf of each banana plant in the plot of each fertilizer experiment was sampled at the stage when the plants were just shooting. The leaf lamina was collected in a bag

TABLE 4. *Effect of Nitrogen Fertilizer on the Yield of Bananas and the Composition of Leaves*

Site	*Level of sulphate of ammonia (applied per plant every 6 weeks)*	*Yield, tons per acre*		*Total nitrogen (per cent. N)*	*Phosphate (per cent. P_2O_5)*	*Potash (per cent. K_2O)*
		1st crop	*2nd crop*			
Grove Farm	N_0 = 0 oz.	5·31	3·56	2·55	0·582	3·68
	N_1 = 2 oz.	6·23*	4·43	2·64	0·475	3·68
	N_2 = 4 oz.	6·58*	4·84	2·76*	0·477	3·66
Orange River	N_0 = 0 oz.	4·77	2·39	2·47	0·567	4·38
	N_1 = 1½ oz.	4·99	3·31*	2·56	0·523	3·79*
	N_2 = 2⅔ oz.	5·48*	3·82*	2·55	9·529	4·07*
Ballards Valley	N_0 = 0 oz.	3·44	..	2·67	0·447	3·52
	N_1 = 2 oz.	3·20	..	2·75	0·447	3·35
	N_2 = 4 oz.	3·42	..	2·72	0·447	3·19*

* Significant at P = 0·05.

and the mid-rib discarded in the field. The bags were shipped to the laboratory where the samples were dried and milled.

Nitrogen was determined by the Kjeldhal method and phosphorus was determined colorimetrically with the use of a Spekker photoelectric colorimeter. The potassium content was determined by precipitation with sodium cobaltinitrite.

Results of field experiments and leaf analyses.—The yields of bananas with different nitrogen applications, and the analyses of leaves from the corresponding plots, are given in Table 4. On the two sites where the application of nitrogenous fertilizers increased yield there was a corresponding increase in leaf nitrogen, which reached the level of significance on one site. At Ballards Valley, where the leaf nitrogen was over 2·6 per cent., there was no response to nitrogen. The results presented suggest that a higher dressing of nitrogen at Orange River would have resulted in a further increase in yield and a correspondingly increased content of nitrogen in the leaf. The application of nitrogenous fertilizer tended to depress the potash content in the leaf on two of the sites.

The results obtained with phosphatic fertilizer appear in Table 5. No response in yield to the application of phosphate was obtained on any

site, and there was no significant increase in the phosphorus content of the leaves. Tentatively, a value of 0·45 per cent. P_2O_5 in the leaf may be taken as the point above which no response is likely to be obtained from the application of phosphate. At Orange River the content of

TABLE 5. *Effect of Phosphatic Fertilizer on Banana Yield and Leaf Composition*

Site	*Level of superphosphate (applied per plant every 6 months)*	*Yield, tons per acre*		*Total nitrogen (per cent. N)*	*Phosphate (per cent. P_2O_5)*	*Potash (per cent. K_2O)*
		1st crop	*2nd crop*			
Grove Farm	P_0 = 0 oz.	5·94	4·13	2·64	0·515	3·59
	P_1 = 2⅔ oz.	6·14	4·58	2·71	0·517	3·68
	P_2 = 5⅓ oz.	6·04	4·12	2·60	0·502	3·65
Orange River	P_0 = 0 oz.	5·3	3·10	2·63	0·518	4·25
	P_1 = 2⅔ oz.	5·09	3·40	2·51	0·518	3·91*
	P_2 = 5⅓ oz.	4·82	3·02	2·44*	0·583	4·08
Ballards Valley	P_0 = 0 oz.	3·32	..	2·70	0·450	3·33
	P_1 = 8 oz.	3·48	..	2·75	0·443	3·38
	P_2 = 16 oz.	3·43	..	2·71	0·448	3·35

* Significant at P = 0·05.

TABLE 6. *Effect of Potash Fertilizer on Banana Yield and Leaf Composition*

Site	*Level of muriate of potash (applied per plant every 6 months)*	*Yield, tons per acre*		*Total nitrogen (per cent. N)*	*Phosphate (per cent. P_2O_5)*	*Potash (per cent. K_2O)*
		1st crop	*2nd crop*			
Grove Farm	K_0 = 0 oz.	6·33	4·92	2·65	0·526	3·64
	K_1 = 4 oz.	5·34*	3·63	2·59	0·531	3·73
	K_2 = 8 oz.	6·40	4·29	2·71	0·477	3·66
Orange River	K_0 = 0 oz.	4·74	2·87	2·47	0·574	3·88
	K_1 = 2⅔ oz.	5·23	3·07	2·53	0·532	3·90
	K_2 = 5⅓ oz.	5·27	3·58	2·59	0·493*	4·46*
Ballards Valley	K_0 = 0 oz.	3·26	..	2·75	0·466	3·30
	K_1 = 4 oz.	3·36	..	2·67	0·430	3·37
	K_2 = 8 oz.	3·46	..	2·73	0·445	3·38

* Significant at P = 0·05.

nitrogen and potassium in the leaf was significantly lowered by phosphate application. It is interesting to note that the lowering of the nitrogen content of the leaf below 2·60 per cent. was associated with lower yields in the same experiment.

In Table 6 the effects of the application of potash fertilizer are set out. The negative yield response to potash application at Grove Farm was

associated with a slight increase in leaf potash and a lowering of nitrogen content below the critical level of 2·60 per cent. At Orange River, where potash fertilizer caused a positive and definite response in yield, over two crops, there was a significant increase in the potash content of the leaves. The nitrogen content of the leaf at this site, although increased slightly by potash application, was still below the critical level of 2·60 per cent. There appears to have been some luxury consumption of potash in this absence of an adequate amount of available nitrogen in the soil. Phosphorus contents of the leaf at this site were distinctly lowered along with the increased uptake of potash.

Generally, it appears that no great response in yield may be obtained from the application of potash fertilizer to plants having a content of more than 3·30 per cent. K_2O in their leaves. Further experimentation is necessary to determine the exact critical level.

Summary and Conclusion

In an attempt to determine the critical levels of the nutrient elements in the leaves of bananas, which can be correlated with fertilizer responses and maximum yield, a preliminary study was made of the optimum time and methods for sampling. This showed that the third leaf in the succession of leaves from the top of the plant was the best indicator of the nutritional status of the plant. The best time for sampling appeared to be as soon as the inflorescence of the plant emerged (the shooting stage).

Samples of leaves, taken as outlined above from three fertilizer field experiments, showed that increased yields could be correlated with increased nitrogen content of the leaf. Where values of less than 2·60 per cent. nitrogen in the leaf were obtained a response to the application of nitrogenous fertilizer could be expected.

The critical levels for phosphorus and potassium content of the leaves could not be estimated so conclusively, because in these experiments there were no significant yield increases with phosphatic or potassic fertilizers. However, 0·45 per cent. P_2O_5 and 3·30 per cent. K_2O may be tentatively regarded as values above which no increased yield is likely to be obtained from the application of phosphate and potash respectively.

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(*Received 5 October 1954*)

CONDITIONS AFFECTING THE NODULATION OF LEGUMINOUS CROPS IN THE FIELD

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AN account was given in an earlier paper [1] of some preliminary field observations on the nodulation of leguminous crops in England and in the tropics. The present paper describes further investigations on similar lines. The experiments were all undertaken at the Oxford University Field Station, and some other observations referred to were made in the Sudan during a visit in 1952–3.

The main experiments were designed to elucidate the following questions:

1. Is nodulation in a leguminous plant affected by the proximity of another plant of the same species, or by a non-leguminous crop interplanted with the leguminous one? Nutman [2] found that nodulation of clover (*Trifolium pratense*), lucerne (*Medicago sativa*), and vetch (*Vicia hirsuta*), grown on agar slopes, was partially inhibited by the presence of another plant of the same species, and sometimes by other legumes or non-legumes, and the hypothesis was put forward that this inhibition might be caused by specific substances secreted by the roots. The problem, however, does not seem to have been investigated under field conditions. In view of American experimental evidence, quoted by Wilson [3], that in interplanted crops of cereals and legumes the yield is greater when both are grown in the same row than in alternate rows, both methods of interplanting were included in the experiments.

2. How far is the damage done by larvae of *Sitona lineata* to the nodules of certain legumes a controlling factor in their development and in the ultimate yield of the crop? This insect feeds upon the nodules of beans (*Vicia faba*) and peas throughout Europe and in Cyprus [4], Egypt (Plant Protection Ltd., private communication, 1953), and French North Africa [5], while related species do similar damage to legumes in North America [6] and Central Asia (Commonwealth Institute of Entomology, private communication, 1952). Observations described in the earlier paper suggested that nodule destruction is an important component of the total damage caused by this genus.

Experimental methods.—Randomly selected plants were carefully lifted with a garden fork, the root system washed, and excess of water removed between cloths; the fresh weights of the whole plants were taken, and the nodules counted (one confluent cluster being counted as one nodule) and detached for the recording of their fresh weight. Full details of the procedure have already been given in the earlier paper [1]. Again it is emphasized that the labour of detaching nodules from plants limited the numbers both of replicates and of plants per plot sample.

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Experimental Results

Effect of number of seeds planted per hole.—Observations were made on plots of dwarf beans (*Phaseolus vulgaris*), planted with one and two seeds per hole, in two seasons; on field beans (*Vicia faba*) in one season, with one to three seeds per hole, at two levels of a nitrogenous fertilizer and two sampling occasions; and on peas (*Pisum sativum*) in one season, with one to three seeds per hole. All the experiments were arranged so that the population of plants per acre remained the same (respectively 32,670 for dwarf beans, 65,340 for peas, and 130,680 for field beans)—either by

TABLE 1. *Mean Nodule Weight when Sown at a Constant Density but with Different Spatial Arrangement* (*g. per plant*)

	One seed per hole	*Two seeds per hole*	*Three seeds per hole*	*S.E.* ±
Dwarf beans, 1953	0·69	0·65	..	0·67
Dwarf beans, 1954	0·10	0·10	..	0·12
Peas, 1954	0·04	0·05	0·06	0·04
Field beans, 1953–4:				
(*a*) Basal dressing of compound fertilizer,				
Sampled Dec. 1953 . . .	0·04	0·05	0·04	0·04
Sampled May 1954 . . .	0·49	0·58	0·58	0·18
(*b*) As (*a*) plus 2 cwt./acre ammonium sulphate,				
Sampled Dec. 1953 . . .	0·04	0·03	0·04	0·05
Sampled May 1954 . . .	0·52	0·48	0·33	0·21

alternating rows with different numbers of seeds per hole or by varying the number per hole within the same row. For the single-row plots, three replications of each treatment were employed, the individual sample being five to nine plants. Where the number per hole varied within the row, fifteen plants from each treatment from at least two rows were compared at each sampling date. The nodule weights per plant for the four experiments are shown in Table 1. The differences between treatments were in all cases slight, inconsistent, and not statistically significant. Thus these experiments provide no evidence that the proximity of another plant affects nodule weight in any of these crops under the field conditions investigated. It is of incidental interest that there was also no significant effect of number per hole on the individual plant weight.

Effect of interplanting with cereals.—In an initial series of experiments in 1952 and 1953 the following combinations of crops were grown: (1) peas and maize, (2) winter-sown field beans and oats, (3) spring-sown field beans and oats, (4) peas and foxtail millet (*Setaria italica*), (5) dwarf beans and foxtail millet. There were three sowing treatments with threefold replication: (*a*) the legume sown alone, at a spacing within the range used by gardeners for hand-sowing such crops, (*b*) legume and cereal sown in alternate rows, (*c*) legume and cereal sown as alternate plants in

the same row; the spacings between and within rows for the last two treatments were a mean between the legume spacing and a normal field spacing for the cereal. In 1954 two further experiments were planted with (1) spring-sown field beans and oats, (2) dwarf beans and spring barley. In these experiments two treatments were compared at a common density, namely, either two plants of the legume, or a plant of the legume and a plant of the cereal, in the same hole. The whole range of experiments thus provided three degrees of proximity between the legume and

TABLE 2. *Effect of Interplanting Non-Leguminous Crops on the Mean Nodule Weight of Legumes (g. per plant)*

(*a*) *Interplanting in alternate and mixed rows*:

	Legume alone	*Legume and cereal: alternate rows*	*Legume and cereal: mixed rows*	*S.E.* ±
Peas with maize	0·06	0·03	0·09	0·025
Winter beans with oats	0·66	0·79	1·04	0·22
Spring beans with oats	1·76	1·92	1·41	0·13
Peas with foxtail millet	0·12	0·08	0·06	0·02
Dwarf beans with foxtail millet	0·30	0·38	0·08	0·15

(*b*) *Two legume, or one legume and one cereal, plants per hole*:

	Legume alone	*Legume with cereal*	*S.E.* ±
Spring beans with oats	1·10	1·01	0·18
Dwarf beans with barley	2·78	2·57	0·92

the cereal plants: in the same hole, in the same row, and in alternate rows. The foxtail millet germinated slowly compared with either of its companion crops, peas and dwarf beans, and thus may not have exerted its full competitive effect at the time when these crops were forming nodules.

The mean nodule weights per plant of the legumes are shown in Table 2. In no instance were there any significant differences between treatments, such differences as did occur being small and inconsistent. Again there is no evidence that under field conditions the proximity of a cereal plant inhibits or otherwise affects the weight of nodules on a legume.

Effect on nodulation and seed production of controlling Sitona attack.—In 1952–3 winter- and spring-planted field beans were sown in plots (10 ft. square) which were separated by 10-ft. paths in order to reduce insect migration between plots. Half the plots were sprayed fortnightly with D.D.T. (Arkotine D. 15), by means of a knapsack sprayer, during the spring and early summer. Five plants from each plot were taken for

examination of the nodules in May–June; the remainder of the plants were left and the yield of seed recorded. In this experiment, as Table 3 shows, treatment with D.D.T. achieved a partial, but not complete, control of Sitona attack on the nodules.

TABLE 3. *Effect of Insecticidal Treatment on the Infestation of Nodules by Sitona Larvae*

Insecticide and crop	*Number of larvae*		*No. of plants in each sample*
	Without insecticide	*With insecticide*	
D.D.T., 1953:			
Winter beans	44	17	20
Spring beans	44	25	20
Dieldrin, 1954:			
Spring beans	100	45	30
Peas	12	13	30

The effect of spraying on the weight of nodules per plant and on the yield of seed per plot is shown in Table 4. Although these figures indicate that the degree of nodulation was enhanced by the insecticidal treatment, only the results for the winter beans reached the level of

TABLE 4. *Effect of Insecticidal Treatment on Nodule and Seed Production*

Insecticide and crop	*Without insecticide*	*With insecticide*	*S.E.* ±
D.D.T.			
Wt. of nodules, g. per plant:			
Winter beans	0·67	1·23*	0·15
Spring beans	0·76	1·22	0·22
Wt. of seed, lb. per 100 sq. ft.:			
Winter beans	6·98	8·58	1·10
Spring beans	12·13	12·85	3·01
DIELDRIN			
Wt. of nodules, g. per plant:			
Spring beans	1·00	1·00	0·21
Peas	0·09	0·13	0·07
Wt. of seed, lb. per 100 sq. ft.			
Spring beans	6·65	6·19	0·53
Peas	6·40	6·97	2·17

* Significant at P = 0·05.

significance. This gain was marked by an apparent increase in seed production, but the standard error was high and the difference from the untreated plots was not significant.

In 1953–4 further experiments were carried out on winter beans, spring beans, and peas, using a different insecticide, Dieldrin. This material was applied to the soil with a knapsack sprayer, for winter beans and peas on 9 April, and for spring beans on 22 April: the rate was

equivalent to 5 lb. of active Dieldrin in 400 gal. of water per acre. Subsequently the soil surface was raked. It was hoped that by this treatment it would be possible to control the attack of Sitona larvae on the nodules only, and thus enable the effectiveness of this control to be estimated without the concomitant control of Sitona adults on the foliage. The plots were slightly smaller than in the previous experiments, only single guard rows were left between them, and there were six replications.

Examination of the winter beans in May showed that there was no attack of Sitona on the nodules, even on the controls, and observations were therefore discontinued. The spring beans and peas exhibited Sitona attack; Table 3 provides evidence that the attack was partially controlled by Dieldrin in the former but not in the latter crop. The weights of nodules and yields of seed for these two experiments are given in Table 4; none of the differences between treated and untreated plots were statistically significant.

On the evidence of these experiments it must be concluded that attack by Sitona larvae on the nodules does not always occur; that, where it does, neither of the insecticides exerts more than partial control; and that even where such partial control is attained, there is no conclusive evidence of an increase in seed production.

Correlation of Nodule Weight and Plant Weight

In the earlier paper [1] it was observed that there was a positive correlation between nodule weight and plant weight in the legumes tested, save for *Phaseolus vulgaris*. Further observations made in the Sudan confirm

TABLE 5. *Comparison of Nodule Weight and Plant Weight of Groundnuts Grown in the Sudan and in Nigeria*

	Mean weight of nodules per plant (*g.*)	*Mean plant weight* (*g.*)
Bunch type:		
Nigeria . . .	0·62	227·7
Sudan . . .	1·54	80·5
Runner type:		
Nigeria . . .	2·01	400·4
Sudan . . .	3·37	147·6

that such a correlation can be found in crops of lubia (*Dolichos lablab*) and of *Phaseolus trilobus*. However, increasing experience makes it plain that the correlation normally occurs only between plants in a single crop or in one plot of an experiment. For different places or seasons, or between plots receiving different treatments in the same experiment, a positive correlation is more rare.

To illustrate the large disparities that may occur, the results for two plots of groundnuts in the Sudan are compared in Table 5 with those obtained in Nigeria [1].

Whereas the Sudan groundnuts, of both bunch and runner type, were more heavily nodulated than the Nigerian specimens, yet the plant weights were in both instances less than half those in Nigeria. Examples of this kind lead to the conclusion that environmental factors often differentially affect nodule weight and plant weight.

The Effects of Age of Plant on the Decay of the Nodules

With annual legumes it is normally found that the weight of nodules rises to a peak at about the onset of flowering, remains static for some time as early and decaying nodules are replaced by those formed later, and finally falls rapidly when nodules decay in the post-flowering phase. This cycle is illustrated by the variable behaviour of quick-growing varieties of peas such as 'Meteor' and 'Pilot' which were used in the present experiments. With early spring planting, the time taken between sowing and emergence or sowing and maturity may vary from year to year. In 1952 plants which reached the mid-flowering stage 56 days after sowing already had half the nodules decayed, whereas in 1950 plants in the same stage of development, but sown 86 days previously, possessed no decayed nodules. Thus the time of decay of the nodules may be somewhat variable, but this appears to be linked chiefly with the varying time taken from sowing to maturity by the host plant.

In this connexion some observations made on lubia (*Dolichos lablab*) in the Sudan are of interest. In the varieties of this crop commonly grown in the north of the country, flowering is induced by the short days of December whether the plants are sown in July or September. Early and late sown plants were examined in December in the early flowering stage, and almost every nodule observed was in some stage of decay. In this instance the nodules apparently had a length of life which was not directly linked with the time taken by the host plant to flower. A further interesting point is that nodulation seems to begin exceptionally early in this crop. Examination of plants sown one month previously showed a mean nodule weight per plant of 0·07 g., or 3·85 per cent. of the mean plant weight—a high figure for any legume, and quite exceptional for one of this age.

The longevity of nodules on perennial legumes is more complex. It is sometimes assumed, and has been stated in textbooks, that such legumes lose their nodules in winter and form new ones in the following summer. One plot of red and white clover (*Trifolium pratense* and *T. repens*), planted in 1951 at the Oxford University Field Station, was examined at monthly intervals through the winter of 1951–2 and until the following May. No signs of decaying or sloughed nodules were observed until April and May, when both were recorded in considerable numbers; however, many of the old nodules were still firm and sound.

Discussion

Two points arising out of these experiments and observations provide material for comment. The observations on groundnuts in the Sudan are in conformity with those made elsewhere by Duggar [7] and by

Masefield [1], to the effect that the runner type nodulates more heavily than the bunch type. These groundnuts were growing at Wad Medani on a clay soil frequently irrigated. Although there were many environmental differences from Nigeria, where nodulation is lighter, the weight of nodules was at least not inconsistent with the suggestion [1] that high soil moisture is a strong predisposing factor to heavy nodulation. It is interesting that with such high nodule weights the plant weights were so small. A possible explanation may lie in the early observations of Nobbe and Hiltner [8], who grew legumes with different proportions of the root systems submerged in water, and found that submerged nodules contributed little nitrogen to the host plant. Similar considerations perhaps account for the marked absence of hydrophytic species among the large family of Leguminosae.

Inhibitory effects on nodulation due to the proximity of other plants, reported by Nutman [2] in laboratory studies, have not been reproduced in these field experiments. Apart from the difference in species used, conditions for the root system in limited volumes of artificial substrate are very different from those in the field. There are numerous instances in the literature when results obtained in pot experiments have not been reproducible in the field. Thus Erdman [9] reported that a number of strains of Rhizobium on soy-beans, which had repeatedly shown high nitrogen-fixing ability in greenhouse tests, failed to increase yield in a field experiment. Aberg, Johnson, and Wilsie [10], working on the effects of association between species of grass and legumes, found that the results of association of the same plants were often reversed between field and greenhouse.

Summary

Field experiments in England provided no evidence that the nodulation of field beans (*Vicia faba*), dwarf beans (*Phaseolus vulgaris*), or peas is inhibited by the proximity of another plant of the same species or a different species (maize, oats, barley, foxtail millet).

Attempts were made through the use of insecticides to prevent damage to the nodules of field beans and peas by larvae of *Sitona lineata* Linn. D.D.T. and Dieldrin achieved only partial control of the larvae, and there was no conclusive evidence that the yield of seed was thereby increased.

In agreement with previous findings for other legumes, positive correlations between nodule weight and plant weight were found in crops of *Dolichos lablab* and *Phaseolus trilobus* in the Sudan. However, similar correlations between the mean figures for crops in different places or seasons, or under different treatments, were found more rarely. It is suggested that environmental factors often affect nodule weight and plant weight differently.

The life-span of nodules normally continues until the host plant passes the peak of flowering. With short-day varieties of *Dolichos lablab* in the northern Sudan, however, the flowering of early sown crops may be delayed until the nodules are already decayed; with this species nodules also appear to be formed exceptionally early.

Acknowledgements.—The author is indebted to Professor G. E. Blackman for his continued interest and encouragement in this investigation; to the Sudan Ministry of Agriculture for facilities; to Dr. M. R. Sampford for statistical advice; and to Shell Chemicals, Ltd., for the gift of chemicals and technical advice.

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(*Received 22 November 1954*)

A STUDY OF MEADOW HAYS FROM THE COCKLE PARK PLOTS

PART I. PROXIMATE CONSTITUENTS AND DIGESTIBILITY

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THE total acreage under hay in England and Wales has remained at a reasonably constant level for the better part of a century. The increased ploughing necessitated by the Second World War occasioned a temporary reduction in this acreage, and the ratio of seeds hay to meadow hay was changed to the advantage of the former. Nevertheless, there remained in 1953 nearly 3 million acres of meadow hay and there is little reason to anticipate a further serious decline in the future. The existence of marginal and high-lying land which, for one reason or another, is never likely to come under the plough sets an obvious limit to such decline. The acreage of permanent grass listed as meadow in the official Agricultural Statistics may not indicate precisely the amount of meadow hay produced in this country, for a certain proportion of this land is undoubtedly mown for the production of silage and artificially dried grass. It is doubtful, however, whether the proportion of the first cut so used is appreciable, or that it will increase. The average yield of meadow hay is just over 19 cwt. per acre, so that, at a conservative estimate, the total annual production in England and Wales is $2\frac{1}{2}$ million tons.

Meadow hay is thus a vitally important home-grown food, not only by reason of the large amount which is produced, but also because this type of hay has certain qualities of its own which cause it to be highly regarded by stockmen. It is usually more palatable than seeds hay and may frequently be of greater mineral efficiency. That it is doubtful whether seeds hay is superior in respect of protein content and starch equivalent value, as is very generally assumed, has been indicated by the work of Smith and Comrie [1] and of Ashton and Morgan [2].

While the effect of particular fertilizer treatments on the yield of meadow hay has long been fairly well understood, it is surprising that so little information on the effect of such treatments on nutritive value is available. This has possibly resulted from the existence of only very few series of meadow-hay plots, the individual members of which have been under consistently different treatment for any considerable time; the permanent meadow is often old and the manurial treatment it receives unvarying. The only experimental meadow-hay plots known to the authors which are, or have been, under constant treatment for a long period of years are those at Rothamsted, Garforth, and Cockle Park. Results derived from the first of these, and illustrative of effects on quality, were reported by Lawes and Gilbert [3], while Crowther and Ruston [4] have described similar effects in the experiment at Garforth. Some work on hays from the Palace Leas plots at Cockle Park was undertaken by Collins [5] as early as 1900, and the same

[Empire Journ. of Exper. Agric., Vol. 23, No. 89, 1955]

worker made further, although rather more limited, investigations in 1905 and 1908. Additional work was done on these plots by Elliott and Thomas [6] in 1934, but investigation was again confined to the hay from a limited number of plots, and there was no detailed examination of ash constituents. Reference should also be made to the work of Fagan [7], who investigated the effect of fertilizers on the chemical composition of hay, although the scope of this work was somewhat limited and the plots did not appear to have been long established.

It was considered worth while to make another investigation of hays from the Palace Leas and to include all those plots which might be considered of general interest. As none of the earlier workers had carried out digestibility determinations *in vivo*, the hays from four selected plots (Nos. 2, 6, 8, and 13) were fed to sheep for this purpose.

Experimental

The Palace Leas meadow-hay plots were laid down by the late Sir William Somerville in 1897, their purpose being to supply material for the study of long-term manurial effects on meadow hay under North Country conditions. At the time of writing (1954), therefore, these plots have been under continuous treatment for a period of fifty-seven years. A part of the field was ploughed in 1918, with the result that the plots, originally $\frac{1}{2}$ acre each, were reduced to $\frac{1}{3}$ acre. The soil is a clay loam overlying the Boulder Clay, but appreciable plot-to-plot differences in profile appearance, structure, pH, and general fertility have resulted from more than fifty years of continuous treatment.

The manurial treatments applied, together with some soil data by Bushnell [8], are shown in Table 1. Farmyard manure has been applied in the autumn, nitrogenous fertilizers in early spring, and other chemical fertilizers in early winter.

In the present investigation the plots were all cut on 30 June 1952, and samples for analytical purposes were taken from the swath on the following day. The procedure employed was to take handfuls at random along the diagonals of the plot and to make these into one composite sample. These composite samples were air-dried and finally given twenty-four hours in an air-oven at 60° C. They were later ground in a Christy-Norris hammer-mill with a $\frac{1}{32}$-inch sieve. Moisture and ash were determined by conventional procedures, true protein by the method of Stutzer [9] and digestible crude protein by Wedemeyer's pepsin-hydrochloric acid method [10]. The procedure described by Thomas and Armstrong [11] was used for the determination of lignin and that of Norman and Jenkins [12] for cellulose. For other proximate constituents the methods specified in the Fertilizer and Feedingstuffs Regulations, 1932, were used.

The hay was baled from pike on 22 July, and two bales were taken at random from each of those plots on which it was proposed to undertake digestibility work. These bales were chopped into half-inch lengths and the product was thoroughly mixed and bagged. Two Blackface wether sheep, $2\frac{1}{2}$ years old, were used for the purpose of the

trials, the procedure employed being that described by Watson and Horton [13]. The metabolism crates were of modern design and allowed sheep to have a clear view of their companions. The collection period was ten days, with a two-day lag. Sheep were weighed before the first trial, in the intervals between succeeding trials and, finally, following the last trial.

TABLE 1. *Manurial Treatments and Soil Analyses, Palace Leas Plots*

Plot No.	*Manures per acre, applied annually unless otherwise stated*	*pH*	*Available* P_2O_5	*Available* K_2O
			%	%
1	8 tons farmyard manure 37½ lb. sulphate of ammonia 50 lb. nitrate of soda 150 lb. basic slag 50 lb. muriate of potash	6·1	0·056	0·016
2	8 tons farmyard manure	5·7	0·016	0·015
3	8 tons farmyard manure, and artificials as for Plot 1, in alternate years	5·7	0·008	0·008
4	8 tons farmyard manure in alternate years	5·6	0·008	0·010
5	16 tons farmyard manure in each fourth year, with artificials in other years as for Plot 1	5·7	0·011	0·014
6	Unmanured	5·1	0·005	0·014
7	150 lb. sulphate of ammonia	4·5	0·005	0·008
8	300 lb. basic slag	5·8	0·011	0·008
9	100 lb. muriate of potash	5·0	0·004	0·030
10	150 lb. sulphate of ammonia 300 lb. basic slag	5·6	0·020	0·009
11	150 lb. sulphate of ammonia 100 lb. muriate of potash	4·3	0·008	0·018
12	300 lb. basic slag 100 lb. muriate of potash	6·1	0·010	0·006
13	150 lb. sulphate of ammonia 300 lb. basic slag 100 lb. muriate of potash	5·3	0·023	0·013

The proximate constituents of the herbage are shown in Table 2. It will be noted that the highest *crude-protein* contents were found in hay from plots which have had either no manurial treatment, or treatment which would generally be regarded as unsatisfactory. Plots which received farmyard manure, with or without chemical fertilizers, produced hay of poor protein content. The intermediate places were filled by those plots which received phosphates. These groupings are

well defined. *True-protein* values fell in approximately the same order, but the three groups were somewhat less clearly differentiated. The ratio true protein/crude protein was highest in plots which received phosphates and lowest where farmyard manure had been applied. In general the digestibility of the crude protein, by Wedemeyer's method, was lowest in those plots which would be considered to have received the best fertilizer treatment.

Plot 7, which received sulphate of ammonia only, had a *silica-free ash* content which was markedly lower than that from any other member of the series. Where potassium chloride was used in addition to sulphate of ammonia (Plot 11), there was an increase in the ash which,

TABLE 2. *Proximate Constituents, Palace Leas Hays*
(*Percentage of dry matter*)

Plot No.	*Crude protein*	*True protein*	*Ratio T.P. C.P.*	*Digestible crude protein*	*Silica-free ash*	*Crude fibre*	*Ether extract*	*N-free extractives*	*Starch equivalent (calculated)*
1	6·67	5·12	0·77	4·41	5·36	29·74	1·47	48·61	42·17
2	6·31	4·88	0·77	4·52	4·69	31·63	1·52	47·69	39·81
3	6·65	5·46	0·82	5·13	4·21	29·93	1·73	49·56	41·91
4	6·48	5·05	0·78	4·10	4·31	30·26	1·54	48·46	41·57
5	5·99	5·08	0·85	4·61	4·68	29·59	1·47	52·07	42·83
6	8·99	7·24	0·80	6·89	4·68	27·66	1·49	50·83	43·42
7	8·12	6·45	0·79	6·33	3·20	27·77	1·64	50·85	43·87
8	7·35	6·87	0·94	5·10	4·14	29·15	1·57	50·08	42·51
9	8·38	7·18	0·86	5·87	4·27	25·89	1·75	51·05	46·28
10	7·74	6·80	0·87	5·51	5·01	29·22	1·42	49·86	42·09
11	7·89	6·74	0·85	6·03	3·72	27·51	1·61	53·43	44·38
12	6·83	6·13	0·90	4·71	4·33	30·28	1·56	49·80	41·30
13	6·99	6·52	0·93	4·50	4·89	27·17	1·54	53·28	45·47

however, was still below that from any of the remaining plots. It is probably significant that the soil of these two plots is of very low pH. A complete fertilizer applied annually, as on Plots 1 and 13, resulted in a relatively high ash content; the effect was particularly well marked where farmyard manure was used in addition to chemical fertilizers.

Plot 13 excepted, the lowest *crude-fibre* contents were found on plots which received no treatment, or else some treatment which consisted in the application of chemical fertilizers other than basic slag. In general the effect of basic slag was to raise fibre content, and of farmyard manure, with or without chemical fertilizers, to increase it to an even greater extent; Plot 2, which received annual dressings of farmyard manure alone, was outstanding in this respect. There was a roughly inverse relationship between *nitrogen-free extractives* and crude fibre.

The *starch equivalent*, calculated from the formula proposed by Watson and Ferguson [14], bore an inverse relationship to crude-fibre content, Plot 2, which had more crude fibre than any other, having the lowest starch equivalent. Farmyard manure and, to a lesser extent, basic slag, lowered starch equivalents.

The results of *digestibility* determinations are shown in Table 3. The organic-matter digestibility of the hay from Plot 8 was slightly higher than that for any of the other three hays, and it seems likely that

the difference was a real one. Digestibility coefficients for the organic matter of Plots 2, 6, and 13 showed very slight differences which were probably within the limits of experimental error.

Crude-protein digestibility was very much lower on Plot 2, and higher on Plot 6, than on the remaining plots. These differences greatly exceeded the variations between the individual sheep. Plots 8 and 13 differed to an extent which was quite unlikely to be of any significance.

With Plots 6 and 13, duplicate sheep failed to give reasonable agreement for the digestibility coefficients of ether extractives, and coefficients obtained for this constituent are not discussed.

TABLE 3. *Digestibility of Chief Constituents, Palace Leas Hays*

	Plot number							
	2		6		8		13	
	Composition as % of dry matter	*Digestibility*	*Composition as % of dry matter*	*Digestibility*	*Composition as % of dry matter*	*Digestibility*	*Composition as % of dry matter*	*Digestibility*
		%		%		%		%
Organic matter	93·99	61·14	94·31	61·96	93·72	63·11	94·80	61·18
Crude protein	6·97	46·81	8·14	53·33	8·01	50·44	7·65	51·89
Ether extract	1·72	57·34	1·63	53·80	1·77	55·98	1·70	56·61
Crude fibre	31·97	63·78	26·64	60·79	28·35	65·37	29·76	62·85
N-free extractives	53·33	61·39	57·91	64·99	55·59	63·98	55·70	61·89
Cellulose	41·39	65·30	38·69	66·37	38·53	69·61	42·04	67·83
Lignin	8·17	3·65	7·89	4·28	8·59	14·94	7·92	6·24
Starch equivalent	40·03		43·64		43·38		44·53	
Digestible crude protein	3·26		4·34		4·04		3·97	

Plot 8 had the highest digestibility coefficients for both crude fibre and cellulose, while both of these constituents were poorly digested in hay from Plot 6. Nitrogen-free extractives were most digestible on Plots 6 and 8. It will be noted that the former plot had the highest content of nitrogen-free extractives and the latter the highest digestibility coefficient for lignin. The digestibility of the lignin from Plot 8 was outstandingly high, but whether there was any real difference on the remaining three plots is doubtful; duplicate sheep on hay from Plot 2 provided very poor agreement.

It will be noted that although hay from Plot 6 had a relatively high starch equivalent, the highest value was derived from Plot 13. The Plot 2 hay was markedly poorer in this respect than hay from the remaining three plots. The agreement between these starch-equivalent figures and those from the same hays arrived at by means of Watson and Ferguson's regression equation [14] was good.

Discussion

The outstanding conclusion reached from a study of the *proximate constituents* of the Palace Leas hays is that the poorer the manurial

treatment applied to a plot, the higher was the quality of the hay, when the quality was assessed from the proportions of total and digestible (Wedemeyer) crude protein and of fibre present and from the calculated starch equivalent.

It is probably unnecessary to say that quality was inversely related to yield. In the present work the better-treated plots were very much more productive than the others. Reference to the Cockle Park Guides shows that the mean yield from Plot 1 (which has been particularly well treated), over a period of fifty-six years, is 46·4 cwt. per acre as against 18·3 cwt. from Plot 6 and 16·2 cwt. from Plot 9; these last two are examples of plots which have not been well treated.

Any attempt to find an explanation for these quality differences must obviously involve some consideration of the herbage species present. It would have been reasonable to expect that on those plots which produce hay of the highest feeding quality there would be a preponderance of the better grasses. The most recent botanical analysis, made by Bushnell [8] in 1951, indicates that the reverse is, in fact, the case, and that the poorer species of grasses predominate on plots which have had poor manurial treatment and are producing hay of high quality. (Any assumption that the better sorts of grasses are, under all circumstances, without a beneficial effect on the quality of hay would of course be unjustified.) In the Palace Leas experiment the sum of clovers and weeds on the poorly treated plots is much larger than on those which have been well done. This point can be illustrated by a comparison of Plots 1 and 9; in 1951 the former contained 90 per cent. of grasses, 2·3 per cent. of clovers, and 1·8 per cent. of weeds, while the latter contained 75·0, 6·9, and 14·3 per cent. of these groups respectively. The grasses on Plot 1 were largely of the better kind, e.g. perennial ryegrass and cocksfoot. On the other hand, Plot 9 had a preponderance of fescues with little or no ryegrass or cocksfoot; the same is true of Plots 6 and 7 which also produce high-quality hay. The possibility that botanical make-up has played some part in determining the quality of the hay cannot, therefore, be ignored. At the same time, while clovers have a significantly higher protein content than do grasses, there is little evidence that the weeds are superior in this respect, although they do tend to contain less fibre. It thus seems unlikely that the sole factor concerned in determining the feeding quality of the hay on these plots is quality difference between species.

The fact that all plots were cut on the same day may have been a major cause of variation, and the plot-to-plot differences in quality which occurred were due, at least in part, to maturity differences. The poorer grasses, e.g. the fescues, being slower starting, would have reached a less-advanced stage of growth at cutting than would such better grasses as ryegrass and cocksfoot. The resulting maturity differences might be large enough completely to outweigh differences inherent in species. At the same time, the effect of phosphatic fertilizers in advancing maturity should not be entirely ignored.

Experience leads to the expectation that the *digestibility* of crude protein would be directly related to its absolute content. On the whole,

this relationship held good. The highest crude-protein content and crude-protein digestibility were found in hay from Plot 6; as already suggested, probably because of its immaturity. The lowest values for both were in hay from Plot 2.

Crude fibre and cellulose may well be considered together in view of the obvious relationship between them. Hay from Plot 6 was distinguished by having crude-fibre and cellulose contents which were as low as, or lower than, hay from any other plot. These findings would be consistent with high quality, but for the fact that the digestibilities of the two constituents were also comparatively low. The same may be said of the content and digestibility of the lignin in this hay. A high protein digestibility would be expected to coincide with good digestibility coefficients for crude fibre, cellulose, and lignin; indeed, the former would normally be a reflection of the latter. While no explanation can be offered for this inconsistency, it may be that the poorer digestibility of the cellular carbohydrate fractions referred to is a characteristic of the poorer herbage species, although no evidence on this point is available. Crude fibre and cellulose attained their highest digestibility in the Plot 8 hay, a fact which may be linked with the weed content. The low cellulose contents of the hays from Plots 6 and 8 can be attributed with some confidence to the large amount of ribgrass present, for Thomas and Rogerson [15] have shown that herbs of this class are typically low in cellulose and crude fibre.

Watson [16], on the basis of his interpretation of Wilson's results [17], concluded that nitrogen-free extractives tend to rise with advancing maturity; the results indicated, however, that the rise is by no means consistent throughout the growing period and is comparatively slight as far as the grasses are concerned. It is therefore doubtful whether any considerable significance can be attached to the fact that the highest content of this constituent was found at Cockle Park on hay from Plot 6. That the digestibility of the nitrogen-free extractives was higher than on other plots can, however, be related to the relative immaturity of the herbage.

The highest starch equivalent was found in the Plot 13 hay, and it is of interest that this was so whether the value were calculated, as here, from determined digestibility coefficients, or by means of the regression equation. The starch equivalent of Plot 2 hay was markedly lower than that of the other three, a fact which can probably be attributed to its more advanced stage of growth. Whether the high starch equivalent of Plot 13 hay can be explained on the basis of slower maturation is doubtful. This latter plot cannot be said to have had unsatisfactory manurial treatment; it may well be that the hay was inherently superior to that from Plot 6 to a degree which masked any difference due to stage of growth. Alternatively, the very mixed character of the grassy fraction of the sward, and the presence of a substantial proportion of clovers, may have been effective in reducing the maturity difference between the two plots.

While the digestibility results presented are limited to four plots, only one of which (Plot 6) had unsatisfactory manurial treatment, they

do provide some support for the assessment of quality which was made on the basis of the proximate constituents. Plot 6 had the highest digestible crude-protein content and was second only to Plot 13 in respect of starch equivalent.

Two factors appear to have been concerned in the better-quality hay produced on those Palace Leas plots which received unsatisfactory manurial treatment. There is, firstly, the species-difference factor. While the better grasses grown by plots which have had good manurial treatment would, alone, give a hay of quality as high as, or even higher than, that from the poorer grasses on the badly treated plots, this effect was probably outweighed by the greater proportion of clovers and weeds grown on the latter. The second factor, that of maturity difference, would also tend to favour the production of high-quality hay on the poorly treated plots. Under practical conditions the first factor would still operate, but it is very unlikely that the second would. While it is impossible to ascertain, with any degree of accuracy, the magnitude of these two effects, the experimental results which have been discussed suggest that poor manurial treatment, or no manurial treatment whatever, can produce hay of reasonably good quality.

Summary

A further study of the composition and nutritive value of hays from the old-established Palace Leas plots at Cockle Park has been made. The proximate constituents of hay from thirteen plots under different manurial treatments were determined, and digestibility trials were conducted for four plots.

When the hays were assessed on the basis of crude-protein content, protein digestibility, and calculated starch equivalent, it was found that plots which had received unsatisfactory manurial treatment produced samples of the highest nutritive value. Plot 6, to which no manures or fertilizers had been applied for more than fifty years, produced better hay than any other plot.

Digestibility coefficients, and starch equivalents calculated therefrom, confirmed that nutritive value was inversely related to goodness of manurial treatment.

It was concluded that two factors, viz. herbage species differences and maturity differences at cutting, were responsible for the production of better-quality hay under unsatisfactory manurial conditions. It was not possible to estimate the relative magnitudes of these two factors.

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(*Received 27 September* 1954)

THE HAIR COAT IN BOVINAE

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WITH PLATE 2

IN both temperate and tropical zones the thermal equilibrium of animals is controlled by the density, length, and colour of the hair coat. The amount of heat loss from the surface of the coat is inversely related to the hair length. Skorohodjko *et al.* [1] have represented this relationship mathematically by the following equation:

$$q = \lambda\left(\frac{t_1 - t_2}{v}\right),$$

in which q = heat loss per unit area in unit time, t_1 = skin temperature, t_2 = hair surface temperature, λ = total coefficient of heat exchange, and v = hair length.

The hairs which cover the body surface are directed in such a way as to form definite 'hair streams', *flumina pilorum*, and at certain points these converge to form vortices, *vortices pilorum* [2]. The type of hair distribution on the skin surface varies with the species. The hairs may either be evenly distributed as in the horse and cattle, or they may occur in groups as in the pig, dog, and cat. In the buffalo the hairs consist of two types: mainly silky and straight, fine, short hairs with a small proportion of large, coarse, straight hairs, the ratio being 1:0·2 respectively [3]. In general, there are three hairs in a group, one of which, the main hair, is larger than the other two. In carnivores a whole bundle of hairs projects from a common follicular opening [4]. The density of the hair coat varies with the species, breed, age, and body region.

The cortex of the hair contains the pigment which gives an animal its characteristic colour; the pigments are either finely dispersed or aggregated in granules. Medullary pigment has little influence on hair colour. Non-pigmented hairs are grey in colour and if they are rich in medullary substance they acquire a bright silvery appearance [5]. The medulla is lacking in the fine cover hairs and the wool hairs of Bovinae. In dairy cattle the hair lumen is filled with marrow substance, but this has not been confirmed in beef cattle [6]. There are also sex, age, and breed differences with respect to the presence and continuation of hair medullation [7].

The morphological characteristics of hair coat are markedly influenced by climate. In the temperate zone cattle have long, dark-coloured, and non-glossy hairs. In the tropics and subtropics the indigenous cattle have short, glossy hairs ranging in colour from grey to fawn and yellow [8]. Hairs are constantly subjected to two processes: shedding and replacement. In Equidae the hair coat is changed twice yearly, being alternately fine and thick. This change is due to the atmospheric temperature and is not simply a seasonal phenomenon [9].

[Empire Journ. of Exper. Agric., Vol. 23, No. 89, 1955]

The present investigation is a comparative study of the density of the hair coat in Egyptian buffaloes and cattle, in different body regions, with particular reference to the effect of age.

Experimental material.—Herds of Egyptian buffaloes and of cattle were available at the Animal Breeding Research Farm, Giza, Egypt; their hair

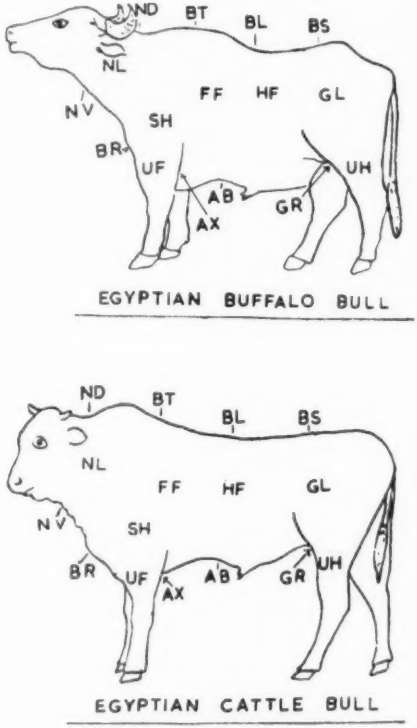

FIG. 1. Body regions in the present investigation: ND, neck (dorsal); NL, neck (lateral); NV, neck (ventral); BT, back (thoracic); BL, back (lumbar); BS, back (sacral); SH, shoulder; FF, fore flank; HF, hind flank; GL, gluteus; BR, breast; AB, abdomen; AX, axilla; GR, groin; UF, upper fore leg; UH, upper hind leg.

coats were examined macroscopically. The skins of three buffalo bulls and three cattle bulls were obtained from Cairo slaughter-house immediately after skinning. The animals were aged some 3 years. Pieces of skin of 10 sq. cm. were cut from sixteen body regions (Fig. 1). These pieces were examined in order to ascertain the structure and distribution of the hairs. To study the effect of age on differences in hair distribution, pieces were taken from one region, the hind flank, of two buffalo embryos (1 month and 5 months old), and from one buffalo calf at birth.

Technique.—The skin specimens were hair-clipped and put in Bouin's fixative for 24 hours. Each specimen was cut into small pieces, of 5×8 mm., the longer axis of each piece being parallel to the slope of the hairs. The pieces were then put into fresh Bouin's solution for another 24 hours. Washing was carried out in 70 per cent. alcohol saturated with lithium carbonate; this lasted for some 8 days, until the yellow colour of picric acid disappeared. Dehydration was in 90 per cent. and 95 per cent. alcohol (24 hrs. in each). The pieces of skin were then transferred twice into fresh terpineol (12 hrs. each time). Embedding in paraffin wax (m.p. = 50° C.) was carried out in a vacuum oven at 9 cm. of mercury. Embedding lasted for 24 hours, the paraffin wax being changed every 4 hours. A rotary microtome was used for cutting serial sections at a thickness of 25 μ, both perpendicular and parallel to the skin surface, or 'vertical' and 'horizontal'. Delafield's haematoxylin and 1 per cent. aqueous eosin were used for staining. Skin pieces of the embryos and calf were treated similarly, the time required being less according to the thickness and toughness of the skin. Embryonic skin was cut at 10 μ, while the calf skin was cut at 15 μ.

The count of hair follicles was carried out using a micro-projector (Leitz Wetzlar) with a ×45 objective lens. It projected a field of 1·28 mm. diameter, as measured by the image of a stage micrometer. One sq. cm. of skin was therefore equal to seventy-eight fields (1·28 mm. diameter). Ten counts were made on the first three horizontal sections from every body region. The number of follicles in each field was multiplied by 78 to obtain the number of hairs per sq. cm. of skin.

Results

Morphology.—In the adult buffalo the hair coat contained two types of hair, the more common type being short, fine, and light in colour, while the other type was long, stiff, and dark in colour. The colour varied along the stem of the same hair, and differed with the body region and age. The newly born buffalo had brown hairs, which changed to dark grey and finally became black with advancing age. In adult cattle the hair coat was usually fawn, and in rare instances it was yellow, brown, black, or spotted (with white, brown, or black patches). In the calf the hairs were lighter in colour, denser, and longer than in the adult.

Histology.—The skin of both species is characterized by the presence of hair-follicle units. Each unit consists of a hair follicle containing one hair shaft only, a *pili* muscle, one or more sebaceous glands, and one sweat gland. In cattle the hair bulbs were at a relatively deeper level, in proportion to the skin thickness, than in buffaloes. In the buffalo the hair-follicle diameter was twice that in cattle (Plate 2, Figs. 2 and 3). The hair-follicle diameter in the adult buffalo was twice that of the calf at birth (Plate 2, Fig. 4). In the buffalo embryo of 1 month old, hair rudiments appeared in the skin (Plate 2, Fig. 5). In the buffalo embryo of 5 months old, the hair follicles were more developed but the shaft was still not formed (Plate 2, Figs. 5 and 6). The *pili* muscle was well developed in cattle whereas in the buffalo it was very thin and the fibres were weakly bound together.

Distribution.—The number of hairs per sq. cm. of skin varied both with the species and with the body region. The mean number was 394 in adult buffaloes and 2,633 in cattle. The minimum number was in the back sacral region in both species (Table 1). The maximum number in buffaloes was in the ventral neck and groin regions; in cattle the maximum number was in the ventral neck, breast (dewlap), and groin regions. In

TABLE 1. *Number of Hairs per Sq. Cm. of Body Surface*

Body region	*Buffaloes*		*Cattle*	
	Range	*Mean*	*Range*	*Mean*
Neck (dorsal) . .	367–460	403	2,207–2,660	2,408
Neck (lateral) . .	413–491	452	1,927–2,806	2,587
Neck (ventral) . .	569–694	616	2,691–4,914	3,471
Back (thoracic) . .	437–647	515	1,786–2,987	2,584
Back (lumbar) . .	296–390	356	1,739–2,590	2,158
Back (sacral) . .	250–320	289	1,505–1,716	1,623
Shoulder . . .	320–499	393	2,956–3,424	3,179
Fore flank . . .	351–601	445	1,381–2,995	2,322
Hind flank . . .	351–499	400	1,474–2,636	2,098
Gluteus . . .	250–406	346	2,145–2,184	2,158
Breast . . .	226–429	338	2,604–3,822	3,466
Abdomen . . .	172–367	278	2,028–3,323	2,569
Axilla	203–413	283	2,028–3,799	2,777
Groin	398–491	442	2,785–3,214	3,011
Upper fore leg . .	320–336	328	2,824–3,822	3,201
Upper hind leg . .	390–452	418	2,488–2,582	2,522
General mean . .	..	394	..	2,633

buffaloes the average density of the hair in the embryo of 1 month old, as measured in the hind flank, was seven times larger than that of the adult. In the embryo of 5 months old it was twenty-five times larger than in the adult. The buffalo calf at birth possessed a hair coat three times as dense as that of the adult (Table 2).

TABLE 2. *Effect of Age on the Density of Hair in Buffaloes*

	Age	*Number of hairs per sq. cm. of skin*	
		Range	*Mean*
Embryo	(1 month)	2,476–3,120	2,880
Embryo	(5 months)	9,868–11,743	10,560
Calf	(at birth)	1,076–1,365	1,248
Adult	(3 years)	387–433	400

Discussion

Buffaloes have scattered hairs which are much less dense than those of cattle. In buffaloes the hairs seem to play a minor role in counteracting high atmospheric temperature. Egyptian cattle have short, glossy, and light-coloured hairs with no felting quality, and this increases the reflectivity of the skin to solar rays. The effectiveness of hair erection in heat preservation is less in tropical and subtropical animals than in

temperate animals because of the shortness of the hairs in the former. The *pili* muscles have no action in buffaloes. Young, growing animals, which have a high metabolic rate that causes excess of heat load, possess a light-coloured hair coat that reflects more efficiently the external heat rays.

There is a decrease in the number of hairs per unit area of the skin with increasing age. The average number in buffaloes is 1,248 in the calf at birth and 394 in the adult (Table 2). The skin area of the buffalo is 6,500 sq. cm. in the calf at birth and 20,400 sq. cm. in the adult. Consequently the total number of hairs for the whole surface area of skin is about 8,110,000 for the calf at birth and 8,040,000 for the adult. It would appear that the decrease in hair density is mainly due to the stretching of the skin with advancing age.

Further investigation is needed to find out the relationship between the degree of hair pigmentation, shedding, and replacement, and environmental factors—mainly climate and nutrition.

Summary.—The structure and distribution of hairs was investigated in Egyptian buffaloes and cattle. Specimens of skin from sixteen body regions were taken from three adult bulls of both species. Similar studies were also made on one buffalo calf and two buffalo embryos. Serial vertical and horizontal sections were cut from each body region, using the terpineol-paraffin-wax method.

The number of hairs per sq. cm. of skin varied with species, breed, individual, sex, body region, and age. Buffaloes have long, stiff, scattered, and dark-coloured hairs, while cattle have short, glossy, dense, and light-coloured hairs. The average number of hairs in 1 sq. cm. of skin, for all the body surface, was 394 in buffaloes and 2,633 in cattle. In both species the minimum number of hair follicles was in the back sacral region while the maximum number was in the ventral neck and groin region; in cattle the breast (dewlap) region also possessed a great number of follicles. Young animals have a lighter-coloured and denser hair coat. The buffalo calf at birth had 1,248 hairs per sq. cm. of skin, and the hair number per unit area of skin decreased with advancing age.

The hair characteristics were discussed in relation to the adaptability of species to tropical climates.

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(*Received 30 September 1954*)

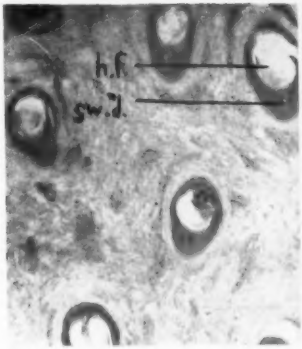

FIG. 2. Buffalo adult (× 48)

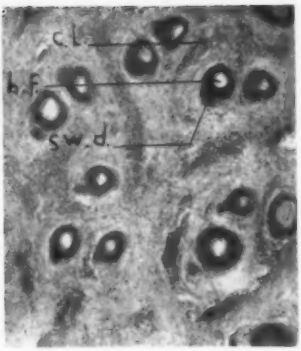

FIG. 3. Cattle adult (× 80)

FIG. 4. Buffalo calf at birth (× 128)

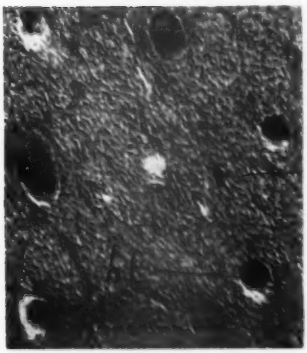

FIG. 5. Buffalo embryo (1 month) (× 128)

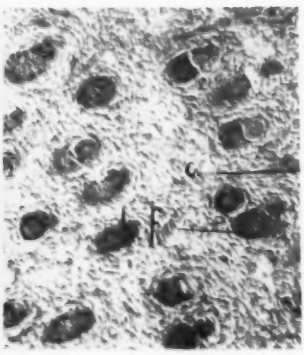

FIG. 6. Buffalo embryo (5 months) (× 128)

FIGS. 2 to 6. Horizontal sections under epidermis. *h.f.*, hair follicle; *sw.d.*, sweat duct

THE CHOICE OF GROUNDNUT VARIETIES FOR PRODUCTION IN THREE AREAS OF TANGANYIKA

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THE present paper is intended to summarize the experience gained in 1947–52 in choosing well-adapted and higher-yielding groundnut varieties, from a collection of introductions, for mechanized production in a dry area of Tanganyika (Kongwa), and to place briefly on record the corresponding experience of 1947–51 in two wetter areas (Urambo and the Southern Province) where rosette disease is an important factor. Since 1951 material of promise in the control of rosette disease has been found [1, 2], and this now offers, in conjunction with other measures, some hope of controlling the disease. The earlier experience is thus of indirect relevance only to the choice of production varieties in those areas.

Considerations of space do not permit the complete results of the fifteen experiments on which this paper is based to be presented in full. The full data [3, 4, 5] are available for reference at the Commonwealth Bureau of Soil Science at Harpenden. The tables of results are cited in the present text by the year and the table number (e.g. 47–48/23).

The management of variety trials.—There are certain inherent difficulties in the use of variety trials for the initial screening of introduced material in a new area. In an ideally executed trial, varieties might well be compared not under strictly uniform conditions, but under the best cultural and agronomic conditions for each. Only in so far as the most favourable ranges of the cultural and agronomic factors overlap, would it be possible to apply uniform treatment throughout. In a new area it is usually necessary to compare different types of material, whose local requirements (as with long- and short-season groundnuts) are not precisely known and are probably different. To test varieties under the most favourable conditions would be a counsel of perfection, which would require the accumulation of agronomic information for several seasons before the critical comparisons could start. In practice, therefore, in the work now reported, uniform conditions representing the best cultural practice attainable at the time had to be used, but this clearly imposed limitations on the accuracy of the initial selections. With increasing experience the field narrowed, as may be seen from the series of experiments at Kongwa.

The yield and other useful attributes of groundnuts are strongly affected by cultural practices. Yield is especially influenced by population and planting date. Close spacing suppresses late flowering or at least renders it ineffective, and so tends to produce more compact fruit-

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[Empire Journ. of Exper. Agric., Vol. 23, No. 89, 1955]

ing, with pods of more even maturity and quality, and with more uniform strength of attachment to the plant. Harvesting at the correct time (which differs with variety) is essential for maximum yield and maximum strength of attachment of the pods. The accurate establishment of plant populations is particularly difficult in a crop so susceptible to seed-bed loss as the groundnut. Because of the degree of uncertainty thus introduced, the conclusions drawn below are somewhat general in character. Rigorous use of significant differences is precluded by the considerations summarized by Healy [6].

A further stage of testing, over a period of years, in which restricted numbers of varieties are compared with a high degree of replication and under closely defined conditions, would be required to select the most useful individual variety or varieties for production. At the same time, the results of Larroque, Chausson, and Galland [7] suggest that the adaptation of introduced material to a new area can be accelerated by suitable pedigree selection methods.

In the present work, varieties gained entry to the trials in the later years on the basis of good performance in observation plots in a previous season.

The classification of cultivated groundnuts, from which the group names used in this paper are derived, has been described by Bunting in a paper to be published shortly.

Kongwa.—The Kongwa area (lat. 6° S., long. 35° E.), in the Central Province of Tanganyika, is at 3,500 to 4,000 feet above sea level. Its mean rainfall is about 20 in. annually, occurring from mid-December to April, with wide variations within the region in any one year and between years. The prevalence of drought years has now led to the virtual abandonment of the area.

In a groundnut variety trial in 1947–8 (47–48/23), a season of favourable rains, the mean yield of four runner varieties was 1,230 lb. of kernels per acre and that of five long-season spreading bunch varieties was 1,300 lb., while eight upright bunch, shorter-season varieties averaged 1,150 lb. The plots of Valencia-type varieties were selectively harvested, in a 5×5 lattice-square design, by wild pigs. None of the upright bunch varieties tested was better than Natal Common, the standard production variety initially chosen for the area.

The 1948–9 season was one of severe drought, and only in the short-season bunch types Natal Common and Valencia were yields over 250 lb. kernels per acre realized in a variety trial (48–49/15·1). Later work in the area was largely confined to the short-season upright bunch forms.

Two trials were conducted in 1949–50, a favourable season (49–50/-15.1; 15.2). The populations established were not uniform, and yield was apparently strongly influenced by population in the ranges concerned (20,000–60,000 plants per acre). However, it was possible to conclude that several Spanish varieties and Barberton could yield as well as Natal Common at comparable populations around 40,000 plants per acre. In this year, also, the Valencia plots were selectively damaged by pigs.

In the seasons 1950–1 and 1951–2, both of which were favourable, three accurate trials, undamaged by pigs, were carried out. The principal

experiment in 1950–1 (50–51/15.1) was planned to compare fourteen Valencia with six Natal-Barberton types. With means of 1,300 and 1,280 lb. kernels per acre respectively, these two groups showed no general difference. Among the Valencias, the local Kongwa Red variety gave an outstanding yield of 1,536 lb. per acre, 120 lb. better than any other variety in the trial. Of the Natal-Barberton group, Gambia bunch (1,400 lb.) was the best. The span of the least significant difference (200 lb.) included fifteen of the twenty-two bunch varieties tested. The long-season spreading and prostrate spreading bunch forms (890–1,140 lb. per acre) were inferior, even allowing for the poor population of two of them.

The second experiment in 1950–1 was designed to compare the performance of certain Spanish types with that of Natal Common, Manyema, and Valencia material (50–51/15.2). The leading places were taken by three Spanish varieties, SR 702, Spanish 205, and Spanish 146, with 1,390–1,480 lb. kernels per acre, and the best of these was 180–200 lb. better than either standard Natal Common or Valencia.

In a highly accurate trial in 1951–2 (51–52/1) the leading varieties of the two trials of the previous year were compared with some additional material. The value of the Spanish types was generally confirmed: their mean yield for six entries was 1,700 lb. kernels per acre, and Spanish 205 and SR 702 gave 1,770 and 1,700 lb. respectively. The yield in the Natal-Barberton group, with a mean of 1,680 lb. kernels, was similar, and the highest yield in the trial, 1,780 lb., was given by a member of this group, PJ 121070. The three Valencia forms yielded considerably less, averaging 1,530 lb. per acre. The best of them was Kongwa Red, at 1,630 lb.

It thus appears that several Spanish types may be expected to yield as well at Kongwa as Natal Common, and therefore deserve more extended study in such dry areas. Although Valencia types are capable of high yields, they were outyielded in 1951–2 by Natal-Barberton and Spanish types, in an experiment which was evidently conducted in extremely favourable cultural conditions. The pods in Valencia varieties appear to be less strongly attached, and the kernels are more liable to germinate before harvesting in Valencia varieties than in other groups, particularly if there is any delay in harvesting at maturity. They are also apparently more susceptible than other types to pig damage. For these reasons Valencia forms cannot be recommended for large-scale production at Kongwa, and further choice for dry conditions in Tanganyika would seem to be confined to the Spanish and Natal-Barberton groups, out of those tested.

Urambo.—The Urambo area (lat. 5° S., long. 32° E.), in the Western Province of Tanganyika, is at 3,500 feet above sea level. Its mean rainfall is about 35 in. annually. There is a short early rains season in October, and the main rains occur from late November to April and May. Variability from year to year is not so serious as at Kongwa, but the length of the season may complicate the harvesting of groundnuts as well as other crops.

In 1948–9, the first season of systematic research at Urambo, two variety trials were heavily damaged by rosette disease and droughty

weather (48–49/15.6; 15.7). Under these conditions of very low yield, short-season upright bunch types yielded better than other types. Runners averaged 63 lb., long-season spreading bunch types 94 lb., and upright bunch types 156 lb. kernels per acre.

In 1949–50 two somewhat inaccurate trials were conducted. In the first of these (49–50/15.9) a number of runner and spreading bunch forms outyielded the three upright bunch types tested, at comparable populations (17,000–25,000 plants per acre), though later information suggests that these relatively low populations put the upright bunch forms at a comparative disadvantage, particularly at the somewhat early planting date of 22 December. The leading long-season bunch types Matevere, Mwitunde Nyasa, Kabompo, and Kenyoma (950–90 lb. per acre) were markedly better than the upright bunches Natal Common (640), variety 809 (680), and Kano (482 lb. kernels per acre).

The second trial in 1949–50 (49–50/15.10) compared several long-season forms with Natal Common at two planting dates, 8 and 27 December. At the earlier planting date the long-season types Matevere, Wima, and Kenyoma (1,200–1,300 lb. kernels per acre at 23,000–30,000 plants per acre) gave higher yields than Natal Common at a considerably higher population (917 lb. per acre at 46,000 plants). At the later date Matevere, Wima, and Kenyoma (811–945 lb. per acre) still yielded better than Natal Common (711 lb.) at comparable populations (26,000–31,000 plants per acre). These results confirm those of the first trial.

In 1950–1, in a trial planted on 18 December (50–51/15.4), the majority of the entries had populations above 40,000 plants per acre. Matevere (1,220 lb.) outyielded all other types, and was markedly better than the majority of the upright bunch types (827–1,094 lb.), of which Natal Common was the best. At the satisfactory populations obtained it is evident that the upright bunch types were able to make a rather better showing than in the previous year. Their mean yield was 991 lb., against 919 lb. kernels per acre for the spreading bunch forms.

The results suggest that at Urambo certain long-season spreading bunch varieties may be more reliable than shorter-season types like Natal Common, particularly in view of the difficulty of ensuring a high population at Urambo, where seed-bed loss was generally high and not easy to control with certainty. The later harvest (120–40 days from sowing in long-season types against 110 days in short-season types), coupled with the dormancy characteristic of the seed of long-season bunch types, is a further advantage of these forms in an area where the long continuance of the rains frequently interferes with the harvest of earlier types. Hemingway [8] has also shown that certain long-season types display resistance to Cercospora (leaf spot) infection, which became very severe at Urambo from 1950 onwards. Finally, it is among long-season bunch types that Evans [1, 2] has found the forms which have promise in the control of rosette disease. The further development of these forms might permit the resumption of groundnut production at Urambo, where it has been abandoned because of the impossibility of controlling rosette and Cercospora in Natal Common by purely agricultural means.

Southern Province.—The Southern Province area of the Corporation, with headquarters at Nachingwea (lat. 10° S., long. 30° E.), is at 1,200–1,500 feet above sea level. The average rainfall is about 35 in. annually, falling in a single season from December to April. In some seasons the later part of these rains has seemed unreliable, and the span is in general not unduly long for the production of short-season groundnuts. In the period with which the present paper is concerned, the experimental station of the area was at Namanga.

A groundnut variety trial was planted rather late in the 1948–9 season, on 15–16 January (48–49/15.11). The short-season upright bunch types gave the best yields, and among them Natal Common, Spanish, and Barberton (1,230–300 lb. kernels per acre) were better than others grown at similar or better populations (30,000–45,000 plants per acre). The longer-season spreading bunch and runner types yielded no more than 940 lb., but as their populations were mostly lower than 30,000 plants per acre and yields appeared to be influenced by population, the question of their comparative yielding capacity remained open.

The trial of 1949–50 (49–50/15.11) was planted reasonably early, on 1–2 January. It was remarkable for very high yields, reaching more than 2,000 lb. kernels per acre. Although the populations were somewhat variable, there was little suggestion that yield was being influenced by population above 15,000 plants per acre, which applied to most of the entries. Natal Common held the leading place, but a number of other upright and spreading bunch types gave not inferior yields. These included the Tanganyika long-season types Mwitunde, Urambo, Matevere, and Wima Bunch.

In 1950–1, the first season in which groundnuts were grown on any scale in the area, Natal Common was selected as the production variety. The variety trial of that year, planted on 8 January (50–51/15.5), gave first place to a group of short-season varieties, including Natal Common, which could not be distinguished from each other by tests of significance. They yielded 1,160–1,400 lb. kernels per acre. No long-season bunch type yielded more than 800 lb.

Up to this stage it appeared that the successful production variety was to be sought among the short-season bunch forms. With the further development of the area, rosette disease, which was originally absent from the Corporation's land although present in African farms some distance away, has increased in importance. While this increase has not yet led to the reduction of groundnut-growing, as at Urambo, it has increased the importance of the Mwitunde types described by Evans. The future of groundnut production, both in the Southern Province and at Urambo, would seem to lie with this material.

Discussion and summary.—For drier conditions, like those of Kongwa, where rosette disease is not of practical significance, the best results in mechanized production are probable with Spanish or Natal Common-Barberton material, of which a number of good lines, including Natal Common itself, are available. Control of Cercospora at Kongwa [8] will have to depend for the present on agricultural sanitation, since long-season types useful for this purpose cannot be relied on here.

At Urambo, where both rosette and Cercospora are severe, the future lies with the development of high-yielding disease-resistant Mwitunde (long-season spreading bunch) material. Short-season forms have been consistently outyielded by long-season spreading bunch types at Urambo.

In the Southern Province, as long as rosette and Cercospora were not dangerous, short-season bunch types of the Spanish and Natal-Barberton groups were the most promising. Now that these diseases have increased, the problem is complex, since the factors for control are present in long-season types which have not hitherto appeared best suited to the conditions. Whether the valuable properties of these types can be found in or transferred to short-season material, or agronomic means found of ensuring the success of high-yielding selections from long-season types, are problems for the future. Their successful solution would be of value for drier areas also.

Acknowledgements.—The authors are indebted to the Overseas Food Corporation and to its Chairman, Mr. Stuart Gillett, for permission to use the data on which this paper is based.

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(*Received 25 November 1954*)

TUBER BRUISING AND POTATO-DIGGER OPERATION

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THE bruising or physical injury of tubers due to mechanical handling presents a serious problem in harvesting and handling potatoes. Hastings [1] stated that 70 per cent. of defects found on inspection of 1,050 cars of potatoes in North Dakota in 1929–30 were attributable to mechanical injury. A later survey in the field indicated that 40 per cent. of the injury was caused by the digger.

Hardenburg [2] in 1933 reported an average of 10 per cent. of tubers dug from 238 New York fields to be bruised or cut by the digger. Similarly, Schrumpf [3] in 1933 reported an average of 28·7 per cent. of tubers bruised by the digging and picking operations in Maine. In 1949 Schrumpf [4] found that the injury from the same operations had been reduced to 11·4 per cent. Much of this reduction may be attributed to improvements in digging-machine design, in particular the use of a continuous elevator chain to replace the shaker-bar or extension elevator commonly used in 1930. According to Hardenburg [5], the development of the continuous-chain type of elevator reduced tuber injury by 35 per cent. This type of potato digger is now used by the majority of the potato-growers in North America.

Several factors affect the amount of injury caused by the digging operation. Among the more important are depth of share, soil cushion on elevator chain, agitation of elevator chain, and padding of deflectors and other projections. Hardenburg [6] reported that injury decreased as the depth of digger share was increased, from 10·8 per cent. with a shallow setting to 4·2 per cent. with a relatively deep setting. He also found that agitation of the elevator chain increased injury from 0·75 per cent. with no agitation to 4·5 per cent. with agitation. Higher elevator-chain speed increased injury from 2·3 per cent. at low speed to 15·0 per cent. in a high-speed setting. Long [7] of North Dakota, in 1944, found that minimum injury occurred at an elevator speed of 220–40 ft. per minute, while a lower or higher speed increased injury. Humphrey [8] of Idaho, in 1950, recommended an elevator speed of 150 ft. per minute or less, and minimum use of kickers or agitators. Todd [9] of North Carolina found that increasing the speed of operation from 1·5 to 3·5 miles per hour increased the damage from 3·4 to 12·7 per cent.

In tests in 1952, at Ottawa, Magee [10] also showed that agitation increased injury, with a conventional elevator potato digger, from 3·1 per cent. with no kickers to 13·5 per cent. with agitation. Another factor that produced a significant change in injury level was the forward traction speed of the tractor. Low-gear operation produced 11·2 per cent. injury while second gear resulted in 5·4 per cent. injury. Since the power-take-off speed of the tractor was the same for each gear, the ratio of the elevator

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[Empire Journ. of Exper. Agric., Vol. 23, No. 89, 1955]

speed to ground speed was reduced, and it was inferred that this reduction in speed ratio produced the decrease in injury.

In 1953 an experiment was conducted at the Central Experimental Farm, Ottawa, to determine the influence of the ratio of elevator speed to ground speed on tuber injury. The field tests were carried out on a reasonably dry Kars sandy soil and three replicated plots with uniform soil conditions were harvested. Each replicate consisted of twelve rows of potatoes 300 ft. long. A split-plot design was used to facilitate management of the machinery in the field.

An International Harvester one-row power-take-off elevator potato digger was used for the test, with an elevator chain 24 in. wide extending 9 ft. from front to rear of the machine. Oblong agitators were used under the chain to ensure soil separation and to provide similar operating conditions to those found on many farms. The digger was driven by a 3-plough tractor to secure a uniform power-take-off speed of 300 r.p.m.

TABLE 1. *Effect of Potato-Digger Adjustments on Injury Index*

Source	*Degrees of freedom*	*Sum of squares*	*Variance*	*F*
Main plots	5	72·8504	..	..
Replicates	2	19·9275	9·9637	2·83
Digger sprockets	1	45·8780	45·8780	13·02
Error (*a*)	2	7·0449	3·5224	..
Tractor ground speeds	1	11·1111	11·1111	3·46
Digger transmission speeds	2	314·4298	157·2149	49·00†
Tractor ground speeds × digger transmission speeds	2	14·3316	7·1658	2·23
Digger transmission speeds × digger sprockets	2	79·0146	39·5073	12·32†
Error (*b*)	23	73·7870	3·2081	..
Total	35	565·5245	..	..

† Significant at P = 0·01

The potato digger was equipped with a three-speed transmission and with two sizes of drive sprocket to control the speed of the elevator chain. The tractor was operated at two forward speeds. These adjustments produced twelve different speed ratios between the ground speed of the digger and the speed of travel of the elevator chain.

A 50-lb. sample of potatoes was taken from each row, a specially lined box being used to prevent further injury to the tubers. These potatoes were stored for approximately 6 weeks, until the injuries had dried and become easily recognized and evaluated.

Each sample was examined for minor injury, major injury, and an over-all estimate of damage referred to as an injury index. The injury index is a factor calculated by multiplying the percentage of tubers with 2–5 per cent. injury by 0·1, with 5–10 per cent. injury by 0·5, and with over 10 per cent. injury by 1·0, and the sum of these three figures represents the injury index. The percentage injury was recorded as the percentage by weight of tuber which had to be peeled from the potato in order to remove the injured area.

Results.—Table 1 presents the analysis of variance of the injury-index readings. The table shows that two factors had a significant influence, namely, digger transmission speeds and the interaction of digger transmission speeds with digger sprockets. Both of these were adjustments made to the digger, and both were highly significant.

Three digger transmission speeds were used. By adjusting the digger transmission into low, intermediate, and high gear, the transmission speed ratio was varied between 0·6:1·0 in low, 1·0:1·0 in intermediate, and 1·4:1·0 in high gear, and this produced similar changes in the speed of operation of the elevator chain.

TABLE 2. *Effect of Digger Transmission Speed on Injury*

Type of injury	*Digger transmission speed*		
	Low	*Intermediate*	*High*
Injury index . .	1·23	3·27	8·28
Major injury, per cent.	4·3	13·3	26·6
Minor injury, per cent.	16·3	40·3	53·9

Table 2 indicates the extent of the injury caused by the various speed adjustments. The results show that all types of injury were seriously increased by an increase in digger transmission speed.

The analysis of variance table also demonstrated that the interaction of digger transmission speeds and digger sprockets was significant. This relationship is shown in Table 3. The fast sprocket gave a normal elevator speed while the slow sprocket reduced the apron speed by

TABLE 3. *Interaction of Digger Sprockets and Digger Transmission Speeds on Injury Index*

Sprockets	*Digger transmission speed*		
	Low	*Intermediate*	*High*
Slow . . .	1·38	2·94	5·07
Fast	1·09	3·60	11·48

approximately 15 per cent. The slower chain speed also resulted in a lower ratio of elevator speed to ground speed. Table 3 shows that with the fast sprocket there was a large increase in injury in the high-speed setting. This was caused by the fast-moving elevator chain and the minimum volume of soil carried on the chain. The slow sprocket at low-speed setting resulted in inefficient operation of the digger, as the soil piled up in front of the elevator chain on the digger share, partially plugging the throat of the digger and bruising the tubers.

These results have demonstrated that an increase in elevator speed produced an increased level of injury. As Fig. 1 shows, this increase in injury was directly related to the ratio of elevator speed to ground speed. The correlation of these results is highly significant, and the '*b*' value

shows that an increase of 1·0 in speed ratio can be expected to increase the injury index by 6·895. The equation for the relationship of injury index to speed ratio is $y = 6{\cdot}89\,x - 3{\cdot}97$.

Conclusions.—The usual recommendation for the ratio of elevator speed to ground speed is 1·1:1·0. However, minimum injury resulted at

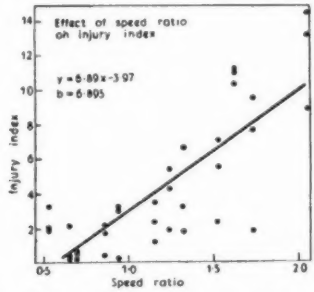

FIG. 1. Effect of speed ratio on injury index.

speed ratios of 0·7:1·0 to 1·0:1·0 on a sandy loam soil. The tuber injury was reduced with speed-ratio reduction until the elevator potato digger operated inefficiently in the field.

From the results of this experiment it can be recommended that an elevator potato digger should be operated with the ratio of elevator speed to ground speed as low as feasible, subject to satisfactory machine operation.

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(*Received 26 November 1954*)

ROTATION EXPERIMENTS WITH COTTON

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IT has been shown repeatedly that crop rotation is of great importance in its effect on yield. Experiments in many parts of the world lead to the conclusion that a suitable system of rotation can maintain or even increase the fertility of the soil, reduce erosion, enable a better and cheaper control of weeds, and assist in fighting insect pests or fungous diseases effectively [1].

With cotton, however, experimental evidence is rather scanty, probably on account of the long-term work needed, although the information available points to the conclusion that rotation may sometimes be quite effective in increasing yield. This has been demonstrated by various workers in the United States, in experiments which there is no need to quote at length. In six southern states, for example, rotation, as compared to continuous cotton, increased the yield of seed cotton by 200 lb. per acre, whereas for cotton preceded by a winter legume cover crop the difference averaged 270 lb. [2]. Similar results have been reported from the Sudan Gezira [3].

On the other hand, rotation proved ineffective in New Mexico [4, 5], and similar results have been reported from Georgia [6]. Sorghum has been shown to depress the yield of succeeding crops not only in the United States [7, 8], but also in India [9] and in the Sudan Gezira [10].

The present work is concerned with cotton rotation experiments carried out in Greece during the last 20 years.

Material and methods.—In 1933 three rotation experiments were laid out in randomized blocks at Sindos, and they have been carried out in the same way ever since. The field used for this work, which had a sandy loam soil, has been under cultivation only since 1928. Before that, it served as grazing land for as far back as information is available.

In 1932 the whole field was planted with cotton followed by vetch which, in 1933, was ploughed under as green manure. The winter crops (wheat and legumes) were sown for the first time in the autumn of the same year.

The rotations studied in each experiment were:

Experiment (a): 2-course rotations

Cotton (C_1)—wheat
Cotton (C_2)—maize
Cotton (C_3)—legume as green manure
Cotton (C_4)—winter legume for seed
Cotton (C_5)—cotton (C_6)

Experiment (b): 3-course rotations

Cotton (C_1)—wheat—winter legume for seed
Cotton (C_2)—maize—wheat

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Cotton (C_3)—wheat—legume as green manure
Cotton (C_4)—cotton (C_5)—legume as green manure

Experiment (c): mixed 2- and 3-course rotations

Cotton (C_1)—wheat
Cotton (C_2)—fallow
Cotton (C_3)—wheat—winter legume for seed
Cotton (C_4)—cotton (C_5)—fallow

In each experiment every replication contained not only the cotton plots but also plots for the alternating crops, so that all stages of the rotation cycles were present each year, and rotational effects may be studied in each of the years after that in which the full rotation became operative. Thus in experiment (*a*) each replication included ten plots, in experiment (*b*) twelve, and in (*c*) ten. The plots were 50 m. long and 2·82 m. (three rows ×0·94 m.) wide, or 141 sq. m. in area. Of the three rows in each plot only the middle rows were used for experimental purposes, the two edge ones being discarded in order to avoid border effects [11, 12]. No fertilizers of any kind have been applied since the beginning of the experiments, which are still in progress.

Besides yield three other characters, namely earliness, lint length, and ginning out-turn, have been studied. All four were determined for each plot separately. The yield is given in lb. of seed cotton per acre, while for earliness the mean date of maturity, as described by Christidis and Harrison [1], is made use of. Lint length represents average length in mm.; it is obtained by means of the Balls' sorter [13], using only the draw box for making a uniform sliver.

A comparatively deep ploughing was regularly given to the field immediately after the end of picking cotton and just before sowing the winter crops; another ordinary ploughing followed in the spring while preparing the seed-bed for cotton. Sowing took place some time during the second half of April, and the crop was always grown under irrigation. Weeds were kept down rather carefully; moreover, after a satisfactory stand was obtained no insect pests or fungous diseases caused serious damage to the cotton.

Results.—In 1941 the conditions prevailing in Greece made it impossible to do any experimental work and thus the whole field was given to cotton. Similarly in 1945 cotton could not be planted on the field, which had to remain fallow. Accordingly, results for 1941 and 1945 being completely lacking, those of 1942 and 1946 for experiment (*a*), and of 1942–3 and 1946–7 for experiments (*b*) and (*c*), are omitted, so that only years involving complete rotation cycles are included. It should be noticed that in experiment (*a*) cotton grown in 1935 or 1936 had been under rotation for only one complete cycle; that produced in 1937 or 1938 for two cycles, and so on. In experiment (*b*) the rotation became operative only in 1936, one cycle extending over the years 1936–8; the same also applies to experiment (*c*).

The yield results so far obtained for all three experiments are given in Table 1 (some have also been reported by Christidis and Harrison [1]).

TABLE 1. *Yield of Seed Cotton in Different Rotations (lb./acre)*

(*a*) *Two-course Rotations:*

	Cycle and year								
	1st 1935–6	*2nd* 1937–8	*3rd* 1939–40	*4th* 1943–4	*5th* 1947–8	*6th* 1949–50	*7th* 1951–2	*8th* 1953	*Mean*
C_1	1,791	1,974	1,583	1,448	1,717	2,111	1,851	1,997	1,796
C_2	1,747	1,895	1,744	1,336	1,592	1,854	1,869	1,967	1,736
C_3	1,938	1,710	1,568	1,522	1,735	2,095	2,030	1,940	1,809
C_4	1,785	1,874	1,659	1,433	1,713	2,060	1,833	2,156	1,792
C	1,914	1,928	1,738	1,284	1,742	2,061	1,990	2,171	1,832
Mean	1,835	1,876	1,658	1,405	1,700	2,036	1,915	2,048	1,793
S.E.*	65·1	93·9	78·6	89·1	79·9	67·3	55·6	161·2	78·1
F†	2·00	1·20	1·32	1·01	0·65	2·43	1·20	0·60	1·69
F‡	2·61	2·61	2·61	2·61	2·61	2·61	2·61	2·84	2·52

(*b*) *Three-course Rotations:*

	Cycle and year					
	1st 1936–8	*2nd* 1939–40	*3rd* 1944	*4th* 1948–50	*5th* 1951–3	*Mean*
C_1	1,776	1,933	1,569	1,889	2,012	1,872
C_2	1,739	1,800	1,575	1,896	2,063	1,856
C_3	1,698	1,912	1,681	1,932	2,182	1,912
C_4	1,617	1,848	1,619	1,909	2,011	1,827
C_5	1,683	2,036	1,640	1,973	2,165	1,931
Mean	1,703	1,906	1,617	1,920	2,087	1,880
S.E.*	42·6	55·2	102·2	59·4	57·6	74·7
F†	2·01	2·64	1·50	0·24	2·03	1·77
F‡	2·61	2·69	3·01	2·61	2·61	2·61

(*c*) *Two- and Three-course Rotations:*

	Cycle and year					
	1st 1936–8	*2nd* 1939–40	*3rd* 1944	*4th* 1948–50	*5th* 1951–3	*Mean*
C_1§	1,357	1,614	1,617	1,491	1,657	1,530
C_2§	1,306	1,672	1,816	1,622	1,415	1,516
C_3	1,445	1,603	1,509	1,515	1,579	1,528
C_4	1,236	1,635	1,709	1,628	1,286	1,452
C_5	1,332	1,648	1,753	1,596	1,642	1,563
Mean	1,335	1,634	1,681	1,570	1,516	1,518
S.E.*	52·9	37·8	77·3	86·2	70·0	94·8
F†	2·11	0·53	1·55	0·54	5·23	1·21
F‡	2·61	2·69	3·01	2·61	2·61	2·61

* Standard error of the values $C_1 \ldots C_2$ in each cycle.
† F observed. ‡ F needed for P = 0·05.
§ The number of cycles for these two-course rotations is higher than indicated.

Since in experiment (*a*) rotations C_5 and C_6 both represent cotton grown continuously on the same field, only the average of both (denoted as C) is given in the Tables. Table 1 involves thirty-nine individual tests, which were analysed both separately and according to their respective

TABLE 2. *Earliness, Lint Percentage, and Lint Length, as Affected by Different Rotations*

(*For basis of measurement see text*)

	Earliness				*Lint percentage*				*Lint length*			
	Cycle and year				*Cycle and year*				*Cycle and year*			
2-course rotations	*6th 1949–50*	*7th 1951–2*	*8th 1953*	*Mean*	*6th 1949–50*	*7th 1951–2*	*8th 1953*	*Mean*	*6th 1949–50*	*7th 1951–2*	*8th 1953*	*Mean*
C_1	11·8	7·7	16·4	11·1	35·1	36·1	35·1	35·9	25·7	27·2	29·0	27·0
C_2	9·9	6·0	13·4	9·0	35·5	35·3	36·0	35·5	25·7	26·8	28·6	26·7
C_3	12·6	7·6	14·4	9·0	35·0	35·1	34·3	34·9	26·1	27·0	28·2	26·9
C_4	13·2	7·5	15·9	11·5	34·6	35·7	34·0	34·9	25·8	27·6	29·2	27·0
C	11·0	7·4	14·7	10·3	35·3	36·2	34·9	35·6	25·9	27·1	28·9	27·0
Mean	11·7	7·2	15·0	10·2	35·1	35·7	34·9	35·4	25·8	27·1	28·8	26·9
S.E.*	0·91	0·77	1·12	0·51	0·41	0·28	0·63	0·27	0·73	0·23	0·26	0·14
F†	1·89	0·85	1·22	3·38	0·73	3·70	1·54	1·71	0·05	0·49	2·24	1·50
F‡	2·61	2·65	2·84	2·84	2·61	2·61	2·84	2·84	2·61	2·61	2·84	2·84

3-course rotations	*4th 1948–50*	*5th 1951–3*	*Mean*	*4th 1948–50*	*5th 1951–3*	*Mean*	*4th 1948–50*	*5th 1951–3*	*Mean*
C_1	13·3	9·9	11·6	34·3	35·4	34·9	26·6	27·9	27·3
C_2	12·1	7·6	9·9	34·5	35·8	35·2	26·5	27·7	27·1
C_3	13·8	9·3	11·6	34·5	35·5	35·0	26·7	27·9	27·3
C_4	12·5	8·5	10·5	34·3	35·7	35·0	26·7	27·4	27·1
C_5	11·9	7·8	9·9	34·1	36·2	35·2	26·4	27·7	27·1
Mean	12·7	8·6	10·7	34·3	35·7	35·0	26·6	27·7	27·2
S.E.*	0·51	0·53	0·44	0·22	0·24	0·27	0·17	0·16	0·16
F†	2·51	3·37	3·93	0·75	1·78	0·23	1·14	1·71	0·53
F‡	2·61	2·61	2·87	2·61	2·61	2·87	2·61	2·61	2·87
2- and 3-course rotations									
C_1§	13·5	12·4	13·0	34·4	35·0	34·7	26·1	27·9	27·0
C_2§	17·5	15·4	16·5	34·0	34·1	34·1	25·7	28·5	27·1
C_3	14·3	13·7	14·0	33·7	34·3	34·0	26·2	27·8	27·0
C_4	16·3	17·3	16·8	33·7	34·2	34·0	26·1	28·0	27·1
C_5	16·0	14·2	15·1	34·0	34·8	34·4	25·7	27·9	26·8
Mean	15·5	14·6	15·1	34·0	34·5	34·3	26·0	28·0	27·0
S.E.*	0·68	0·43	0·50	0·21	0·17	0·15	0·17	0·16	0·18
F†	3·61	17·87	10·21	1·85	6·65	4·55	2·13	0·32	0·42
F‡	2·61	2·61	2·87	2·61	2·61	2·87	2·61	2·61	2·87

*, †, ‡, §: see references in Table 1.

cycles. Out of the thirty-nine tests, six reached the level of statistical significance, but their results were entirely inconsistent. When studied in cycles, significance, as shown in Table 1, was reached only once out of eighteen cycles, and never for the marginal mean values.

Regarding earliness, ginning out-turn, and lint length, these characters have been studied particularly during the last 6 or 7 years. The results obtained are summarized in Table 2, which involves fifty-one individual tests. Out of them nine gave results slightly significant, but apparently

meaningless. Here again, when the results were studied in rotation cycles (tests belonging to the same cycle are subject to similar rotational effects), in very few cases did they reach the level of statistical significance. In all three experiments, however, the differences between the mean values for earliness, although slight, proved clearly significant.

Discussion.—The results in Table 1 lead to the conclusion that the different rotations studied have not so far had any appreciable effect on yield. In experiment (*a*) the C plots have been sown continuously with cotton since 1934 (actually, for 19 years). Their average yield, however, proved as good as (if not better than) that from plots where cotton alternated with fallow, legumes, or green manure. There has not been the slightest indication that, under the conditions of these experiments, the continuous cultivation of cotton on the same field has resulted in any reduction in yield. Similar conclusions may be reached from experiments, (*b*) and (*c*). Cotton after fallow, legumes, wheat, or maize, or growing on the same field two years out of each three, gave essentially the same yield.

With regard to lint percentage or lint length, here again there is no indication that these characters have been appreciably affected by the rotations used (Table 2). The results for earliness were somewhat erratic on account of their great variability, but they suggested that cotton after fallow, green manure, or winter legume for seed may be somewhat later to mature than after other crops.

It may appear remarkable that rotation proved ineffective in increasing yield or affecting other economic characters of cotton. It should be remembered, however, that these experiments were laid out on old grazing land which had been under cultivation only since 1928. Twenty-five years may not be a sufficiently long time to bring about an appreciable deterioration in the physical or chemical properties of the soil. Weeds were also kept properly under control, and pests and diseases did not constitute a problem. Under such conditions it is less surprising that the effects of rotations should be small or negligible for the time being, but they might, before long, become quite important.

Results similar to the above have also been reported from the United States. In New Mexico, cotton grown continuously on the same field for 8 years did not show any reduction in yield [4]; later work also indicated that rotation with annual legumes or non-legumes was not profitable, but lucerne and sweet clover might be expected to increase cotton yields in most cases [5]. In Georgia, continuous cotton from 1931 to 1946, on fertilized land, yielded about the same as cotton grown in any rotation system studied, with or without legumes [6].

Summary.—In three experiments carried out annually at the Hellenic Cotton Research Institute from 1933 to 1953, cotton grown in different rotations, of varying length, did not differ in yield, lint percentage, or lint length from cotton grown continuously on the same field for 19 years. There was, however, a slight but definite effect on earliness.

The land had been under cultivation only since 1928; previously it was grazed. Further, the crops were not seriously affected by weeds, insect pests, or fungous diseases. These conditions may account for the lack of benefit from crop rotation.

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(*Received 21 September 1954*)

THE DIRECT EFFECT OF TROPICAL CLIMATE ON THE PERFORMANCE OF EUROPEAN-TYPE CATTLE. I. GROWTH

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WITH PLATES 3 AND 4

IT has been estimated by competent authorities that some two thousand million of the world's population would be greatly improved in nutritional status by the provision of milk or milk solids in their diet [1]. A very large proportion of this milk-deficient group of people resides within the tropical regions, in which it is notoriously difficult to rear and maintain high-producing European-type cattle. Yet these same regions represent one of the few remaining large areas of land that appear capable of greatly increasing in productivity. Thus an urgent problem facing agricultural technology is to find ways and means of increasing the productivity of cattle within the tropical zone.

Animal husbandmen have generally accepted the dictum that European-type cattle do not thrive in the tropics. This usual lack of thrift has been attributed to direct climatological effects, to an indirect effect through poor nutrition, or to both. In endeavours to sort out the precise causes of unthriftiness, it has become clear that differences in heat tolerance occur between breeds [2, 3, 4]. Little is known, however, of the relative heat tolerance of individuals of the same breed, and for this reason it has not been possible to gauge, accurately, the possibility of successfully selecting from European cattle a type of animal that would suit tropical conditions.

To throw light on some of these problems, an experiment was begun in 1950 as a co-operative undertaking between the Departments of Agriculture of New Zealand and the Crown Colony of Fiji. Eight sets of identical-twin heifer calves, born and bred in New Zealand, were used as experimental material. As calves, the twin sets were divided and the odd-numbered members of each set were sent to Fiji, while their even-numbered co-twins remained in New Zealand. Before the experiment started, a strict feeding and management system was laid down in order to make all environmental (except climatological) factors as uniform as possible. Thus, genetically identical animals were subjected to two environments which were essentially identical in all details except climate. The investigation aimed at providing a clear-cut measure of the direct effect of tropical climate on the performance of European-type cattle, and, further, at indicating whether in the population the twins were drawn from there existed individuals possessing markedly superior heat tolerance.

Experimental

Locality and climate: (*A*) *Fiji.*—The main island of the Fiji group, Viti Levu, is situated in lat. 18° S., long. 178° E. The Government

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[Empire Journ. of Exper. Agric., Vol. 23, No. 89, 1955]

Research Station at which the work was carried out is located at sea-level near Sigatoka township, on the south coast of the island.

The climate may be classified as hot and humid. The annual average maximum, minimum, and mean temperatures, relative humidity, absolute humidity, and total rainfall, over the period April 1950 to July 1952, are shown in Table 1. Tables for the individual monthly means during this period have been deposited with the Editor and are available on request.

The temperature trends over the period chiefly concerned are plotted at four-weekly intervals in Fig. 1.

While the maximum temperatures rarely exceed 90° F., the annual and diurnal fluctuations are relatively small in Fiji as compared with

TABLE 1. *Annual Mean Climatological Data over the Period April 1950 to July 1952*

	Sigatoka	*Ruakura*
Average maximum temperature (° F.) . .	83	65
Average minimum temperature (° F.) . .	68	44
Mean temperature (° F.)	75	54
Average relative humidity (per cent.) . .	80	84
Average absolute humidity* . . .	118	57
Total rainfall (in.)	74·2	37·7

* Grains moisture per lb. dry air.

New Zealand. Sigatoka is situated on the border between the dry (northern) and the wet (southern) zones of the island. In general the heaviest rainfall occurs in the hottest part of the year, thus aggravating the difficulties caused by high temperature. A relatively comfortable period occurs, however, in the winter (June–September) when not only are temperatures lower but rainfall also is low.

(*B*) *New Zealand.*—Ruakura Animal Research Station is situated in the North Island of New Zealand, approximately in lat. 37° 50′ S., long. 175° 18′ E., and at an altitude of 130 ft. Dairy cattle are normally kept on pasture all the year round, for the climate is temperate with a moderately high rainfall and high relative humidity. Fairly heavy night frosts occur frequently over the period mid-June to mid-August. In comparison with the Fiji climate temperatures are much lower, the maximum daily temperature barely exceeding the minimum temperature at Fiji (Fig. 1). The annual and diurnal fluctuations are greater at Ruakura than in Fiji. The relative humidity is approximately the same in the two places but the absolute humidity is naturally much lower in New Zealand.

To compare the direct effects of the two climates on the animal, the 'climographs' in Figs. 2 and 3 are shown. Fig. 2 is constructed according to Wright's method [5], by plotting the monthly mean dry-bulb temperatures against the monthly mean relative humidities. The resulting points are joined to form a diagram, the shape and area of which reflect the summated environmental conditions. Lee [6] pointed out that absolute humidity was more important than relative humidity from the point of view of the effect on the comfort and well-being of homothermic animals.

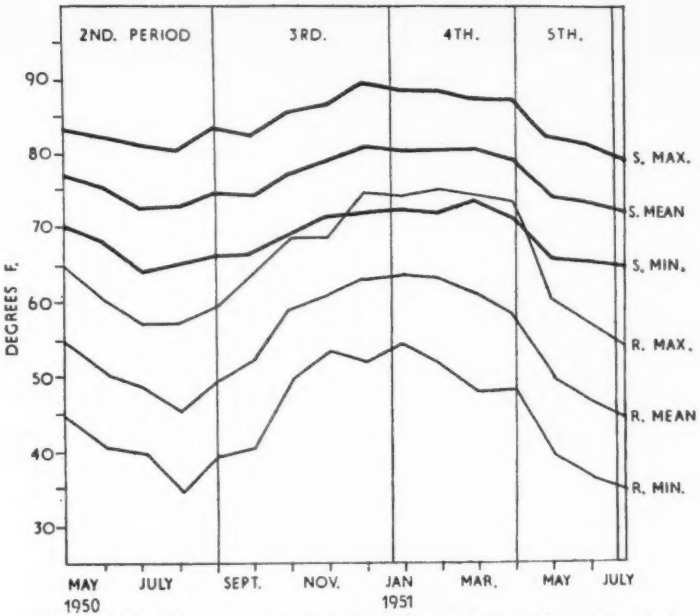

FIG. 1. Monthly mean temperatures during main experimental period (S = Sigatoka, R = Ruakura).

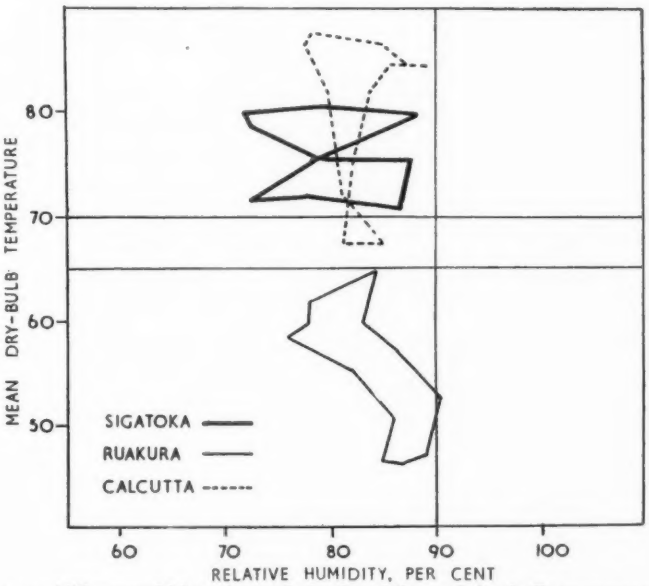

FIG. 2. 'Climograph' based on relative humidity and dry-bulb temperature.

The climograph in Fig. 3 is constructed using absolute humidity. It is clear from Figs. 2 and 3 that the climates of Fiji and New Zealand are very different; indeed, the climograph of Fiji resembles that of Calcutta (also shown) which, according to Wright, is sufficiently severe to cause dwarfing even in indigenous cattle. In contrast, it is known that the progeny of cattle imported to New Zealand from Europe tend to grow to a greater size than in the country of their origin, which indicates that the

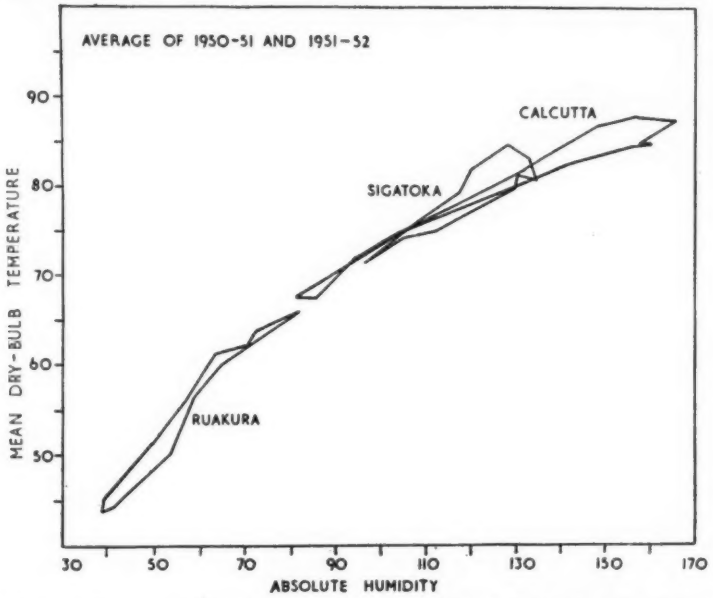

FIG. 3. 'Climograph' based on absolute humidity and dry-bulb temperature.

climate of New Zealand is sufficiently favourable to permit maximum growth of European-type cattle.

Animals.—The eight sets of identical cattle twins used were selected from a herd of twenty-five sets. A sample was aimed at in which the animals were of as similar age as possible. Selected this way, and born in the height of the calving season, the animals may be considered a random sample of the dairy cattle in the Waikato district of New Zealand. Table 2 shows the tattoo numbers, birth dates, predominant breed, and coat colour of the twins. During early life the calves were reared as described by McMeekan [7].

The odd-numbered animals were shipped to Fiji when they were approximately $7\frac{1}{2}$ months old, the even-numbered animals remaining in New Zealand. The passage, which lasted $3\frac{1}{2}$ days, was fairly rough. On arrival the animals were quarantined in Suva for 10 days, finally arriving in Sigatoka a fortnight after having left Ruakura. Throughout this time they were fed on lucerne hay and barley meal, which represented a

radical change from their previous diet of pasture alone. The rigour of this voyage, and the sudden change of diet and climate combined, caused a sharp initial setback in the condition of the calves. The appearance of representative twins at separation and subsequently is shown in the Plates (Figs. 8 and 9).

General management and feeding.—The following account applies equally to the animals at both Ruakura and Sigatoka, unless otherwise mentioned.

The calves were kept outside day and night except between the hours of 6 to 8 a.m. and 3 to 5 p.m., when they were brought inside to an open shed for feeding. The yard was kept free from all vegetation. Shade was provided throughout the day by trees, and free water intake was allowed through self-feeding troughs.

TABLE 2. *Description of Sets of Identical-twin Calves*

Tattoo number	*Birth date (1949)*	*Breed*	*Coat colour*
17–18	17 July	Grade Jersey	Dark
23–24	28 July	Grade Jersey	Dark
25–26	27 July	Grade Shorthorn	Dark red
29–30	24 July	Jersey-Shorthorn	Light red
33–34	30 July	Grade Jersey	Medium
39–40	2 August	Grade Jersey	Medium
45–46	3 August	Grade Jersey	Dark
47–48	4 August approx.	Grade Jersey	Light

Feeding was carried out in individual bails so that feed consumption could be accurately measured for each individual. The fodder consisted of lucerne hay and barley meal grown in New Zealand, and extracted copra meal manufactured in Fiji. When acquired each batch of hay and barley meal was halved, one-half remaining at Ruakura, the other being shipped to Sigatoka. The copra meal was handled similarly.

The general plan was to allow an *ad lib.* intake of hay but to restrict meal (barley and copra in the proportion of 4 to 1) to 1 per cent. of body-weight. Cod-liver oil was mixed into the meal in sufficient quantity to prevent the remote possibility of vitamin A and D deficiency occurring. Steamed bone meal and rock-salt were provided in the yards from 12 February 1951 onwards.

Measurements recorded.—In the present paper the growth and feed intake are considered over the period from the time when the twin sets were separated (6 March 1950) to the time when the effects of the first pregnancy on growth became important (taken arbitrarily as 25 June 1951).

The following measurements were taken at weekly intervals: (1) weight (lb.); (2) height over withers (cm.); (3) chest girth (cm.); (4) belly girth (cm.); (5) chest depth (cm.); (6) hip-pin distance (cm.); (7) hip–hip distance (cm.).

Consumption of hay and meal was computed as weekly totals for each heifer. The feed (at Ruakura only) was sampled daily and a chemical

analysis was carried out fortnightly on bulk samples. It was found that both hay and meal varied very little in composition over the whole length of the trial.

Water was provided in self-feeding troughs, and at pre-set intervals (first monthly, but later weekly) the water consumption for each animal was measured separately. On these occasions the water trough was covered and the animals were allowed into the bails every four hours and given water *ad lib*. The strangeness of this procedure caused spuriously low water intakes for a time. For this reason the first three series of results on water intake have been omitted.

Results

The period of growth analysed and discussed in the following pages began at the time of separation of the twins at an average age of $7\frac{1}{2}$ months, and ended when they were approximately 2 years of age. All animals became pregnant within a fairly narrow time period but none had calved at the end of the last period. No corrections for pregnancy have been made. A final figure for weights and linear body measurements attained towards the end of the first lactation, when the twins were approximately $2\frac{3}{4}$ years old, is also given. Unless otherwise stated, all body weights and measurements given in the tables or shown diagrammatically were 'smoothed' by taking five-weekly moving averages. The average growth curves of the twins in New Zealand and in Fiji, together with the temperature and feed-intake curves, are shown in Fig. 4.

A preliminary inspection of the live-weight increment (compare Fig. 5) indicated that the growth period could be divided into five fairly distinct phases:

	From	*To*
1st phase . . .	6 March 1950	1 May 1950
2nd phase . . .	1 May 1950	21 August 1950
3rd phase . . .	21 August 1950	1 January 1951
4th phase . . .	1 January 1951	2 April 1951
5th phase . . .	2 April 1951	25 June 1951

The first phase (during which the twins were in transit) was characterized by a marked loss of weight in the Fiji twins. This, however, was largely regained in the second phase when the Fiji twins grew at a faster rate than their New Zealand mates. In the third phase the growth rates of the two groups were similar, as shown by the parallel curves, but in the fourth phase there was a marked deceleration of growth rate in the Fiji animals. In the last phase growth rates were again similar.

A statistical summary of live weights and body measurements is presented in Table 3.

Live-weight changes.—Records of the live weights of all animals at the beginning of each of the five phases, at the end of the last phase, and at the end of lactation are available, and copies have been deposited with the Editor. So have the corresponding average weight differences (absolute and percentage) between the New Zealand and Fiji animals.

The continuous trends (on a weekly basis) of the average live weights,

TABLE 3. *Statistical Summary, Live Weights and Body Measurements*

d = mean difference, Ruakura—Fiji (log. basis)
d′ = mean difference adjusted for previous period (log. basis), indicating growth rate
s = significance of between-set differences, adjusted for previous period except for first period

Characteristic	*Date*	*6 March 1950 Pre-experimental*	*1 May 1950*	*21 August 1950*	*1 January 1951*	*2 April 1951*	*25 June 1951*	*28 April 1952 (7 sets only)*
Live weight	d	45±113	651†±111	302*±115	131±124	507†±101	433†±101	178±127
	d′	..	615† (72)	59 (116)	−154 (65)	411† (46)	−66 (22)	−128 (108)
	s	†	N.S.	N.S.	?	†	*	N.S.
Height	d	27±28	53?±27	102*±31	110†±25	134†±20	125±19	54±27
	d′	..	35 (21)	49? (17)	41 (14)	75? (16)	10 (9)	−68 (17)
	s	†	N.S.	N.S.	?	N.S.	N.S.	N.S.
Chest girth	d	30±39	97*±32	102?±46	131†±34	233†±35	281†±44	158†±37
	d′	..	78* (22)	7 (36)	69* (21)	148* (29)	0 (14)	53 (35)
	s	†	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Belly girth	d	5±61	150*±63	−132*±50	−55±76	109±57	206*±73	348*±96
	d′	..	145† (29)	−196* (45)	112 (45)	140* (41)	80? (33)	146 (64)
	s	†	*	N.S.	N.S.	N.S.	N.S.	N.S.
Chest depth	d	10±37	86?±41	121*±42	103*±28	81*±29	149†±37	36±40
	d′	..	78* (30)	62 (33)	28 (12)	−16 (13)	52* (14)	−85? (21)
	s	†	N.S.	N.S.	*	N.S.	N.S.	N.S.
Hip-pin distance	d	24±36	148†±32	180†±30	326†±31	331†±25	382†±28	151†±28
	d′	..	129 (16)	70† (21)	169 (17)	136 (19)	21 (7)	36 (28)
	s	†	N.S.	N.S.	N.S.	N.S.	*	N.S.
Hip–hip distance	d	−3±69	160*±57	190†±47	196†±44	212†±38	251†±30	97*±31
	d′	..	162† (17)	91 (33)	27 (15)	64 (20)	96† (12)	−17 (29)
	s	†	†	†	N.S.	N.S.	?	N.S.

Notes: 1. Levels of significance: ?, P = 0·10; * P = 0·05; † P = 0·01; N.S. = not significant (between-set differences).
2. Figures in parentheses represent the 'adjusted' standard deviation, not the standard error of the adjusted differences.

and the percentage differences, are shown graphically in Fig. 5, while the average weekly live-weight increments and the smoothed live weights are given in Table 4. The average weekly increments during the whole period of phases two to five inclusive were: New Zealand, 8·0 lb.; Fiji, 7·5 lb.; difference, +0·5 lb.

The second phase, in Fiji, was characterized by relatively low temperatures and a sharply increasing feed requirement. The sharp fall in feed

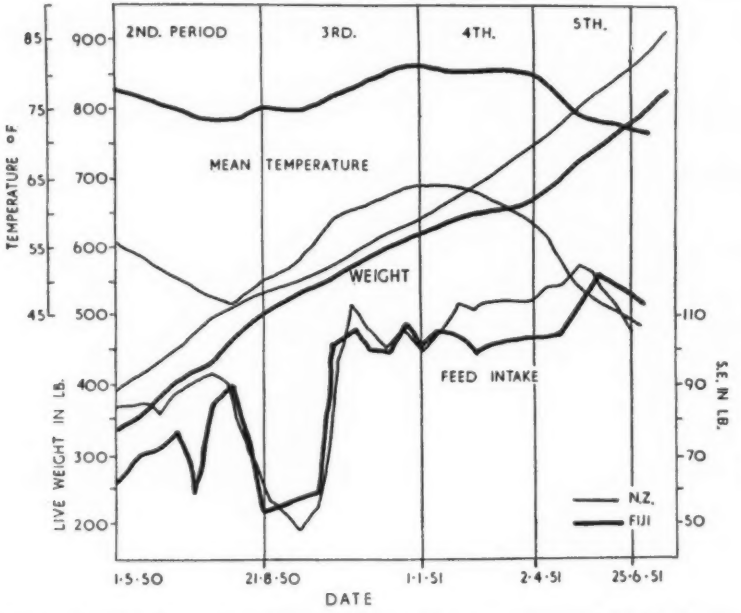

FIG. 4. Average live-weight growth curves, with temperature and feed intake, at Ruakura and Sigatoka.

intake (Fig. 4) in the middle of this period was due to a delay in the shipment of meal from New Zealand. Thus, it seems that the climate in Fiji over the period was sufficiently favourable to allow the heifers to overcome almost wholly the initial check brought about by the sudden change in environment.

In the third phase the Fiji twins continued to grow at a slightly faster rate than their New Zealand mates. As a consequence, body-weight differences between the groups had almost disappeared at the beginning of the fourth phase. The good growth rate made by the Fiji twins over the third phase was quite remarkable for two reasons: (1) temperatures rose steadily to their peak level for the year; and (2) feed intake was severely curtailed, as during half of the period no meal was offered either group of heifers. This procedure was adopted in an attempt to stop the animals from getting too fat at the time of mating, for other work at

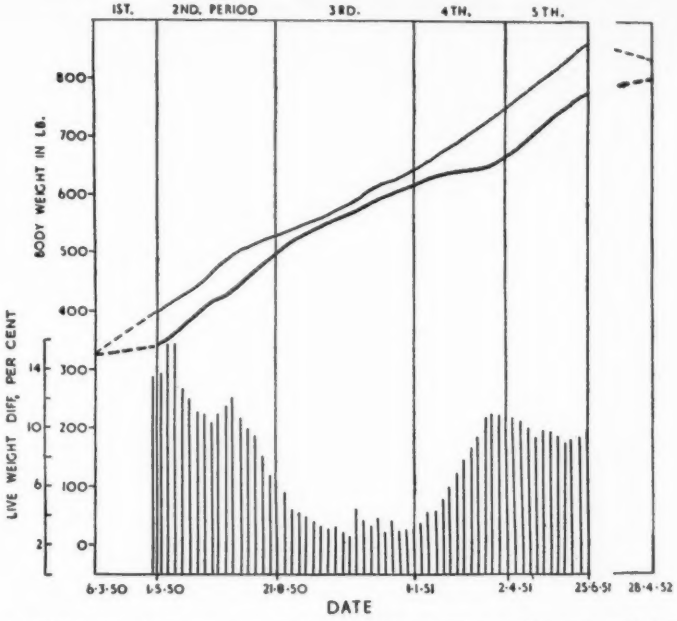

FIG. 5. Differences between average live weights of twins at Ruakura and Sigatoka, expressed as per cent. (Live-weight curves also shown.)

TABLE 4. *Average Weekly Live-weight Increments during Growth Phases, with Live Weights at Beginning and End of Phases*

(*pounds*)

	Phase					*End of phase 5*	*End of lactation*
	1	*2*	*3*	*4*	*5*		
LIVE-WEIGHT CHANGE:							
New Zealand . .	..	8·6	5·9	8·5	10·1	..	..
Fiji	..	9·7	6·7	3·5	10·5	..	..
Difference . .	..	−1·1	−0·8	+5·0	−0·4	..	..

	Beginning of phase						
SMOOTHED LIVE WEIGHT:							
New Zealand . .	323	393	530	643	752	873	837
Fiji . . .	322	340	495	623	668	789	804
Difference . .	+1	+53	+35	+20	+84	+84	+32

Ruakura had suggested that heifers in a high condition prior to, and at the time of, mating are more difficult to settle in calf than if they are thin [8].

The curtailment of meal feeding definitely retarded the growth rate of

the New Zealand twins, but had less effect on the Fiji twins. This observation naturally raises the question of the true nature of the observed growth of the latter animals during this period. The results appearing in Figs. 5 and 6 (average curves of live weights and linear measurements) show that while the body-weight differences between New Zealand and Fiji twins declined up to the beginning of the fourth phase, the differences in linear measurements increased. The outstanding exception to this was the belly girths. At or near the beginning of the second, the third, and the fourth phases the belly girths of the Fiji twins were greater than those of their New Zealand co-twins. The reason for the relatively rapid increase of this measurement may be sought in the fact that the water consumption of the animals held in Fiji was twice as great as that of the New Zealand twins (Table 11). Thus, a part of the weight gained over these two phases by the Fiji twins may have consisted of a greater fill of water.

In the fourth phase a sharp retardation of growth occurred in the Fiji twins. As a result, the weight difference between the groups reached 83·8 lb. at the beginning of the fifth phase; this was the largest difference so far, although it was smaller on a percentage basis than in the beginning of the second phase. The fourth phase was characterized in Fiji by persistently high temperatures. In the fifth phase the growth rate of the two groups was practically identical. The temperature began to drop in Fiji at the beginning of the period and there was an associated, although not immediate, increase in feed intake.

At the end of the pre-lactation growth period (arbitrarily defined by the date of 25 June 1951, when the twins were approximately 2 years of age) the average weight difference was 84·1 lb., or 9·6 per cent. This does not represent, under New Zealand conditions, a very serious depression in body weight at the time of first calving. Work at Ruakura [9] has shown that much greater body-weight differences (approximately 21 per cent.), due to under-nutrition, resulted in only a 5 per cent. decrease in milk and butter-fat production if the heifers were fed adequately after calving. Moreover, the effects of such differences on mature body weights and on production from the third lactation onwards have been shown to be negligible. It is important, therefore, to note that in the present investigation the body-weight differences towards the end of the first lactation were small, amounting to only 32 lb. or 3·9 per cent.

The weight differences between the groups were statistically non-significant (Table 3) at the beginning of the first and fourth phases and at the end of the first lactation. Apart from the first phase, the only time when the differences in growth rate were significant was during the fourth phase, when the Fiji twins grew more slowly (average increment 46 lb.) than did their New Zealand co-twins (average 110 lb.).

Linear body measurements.—Records of the measurements and the group differences, for height over withers, chest girth, belly girth, chest depth, hip-pin distance, and hip–hip distance, referring to the same points of time as the body weights, have also been deposited with the Editor. The average growth curves for all six measurements are shown in Fig. 6.

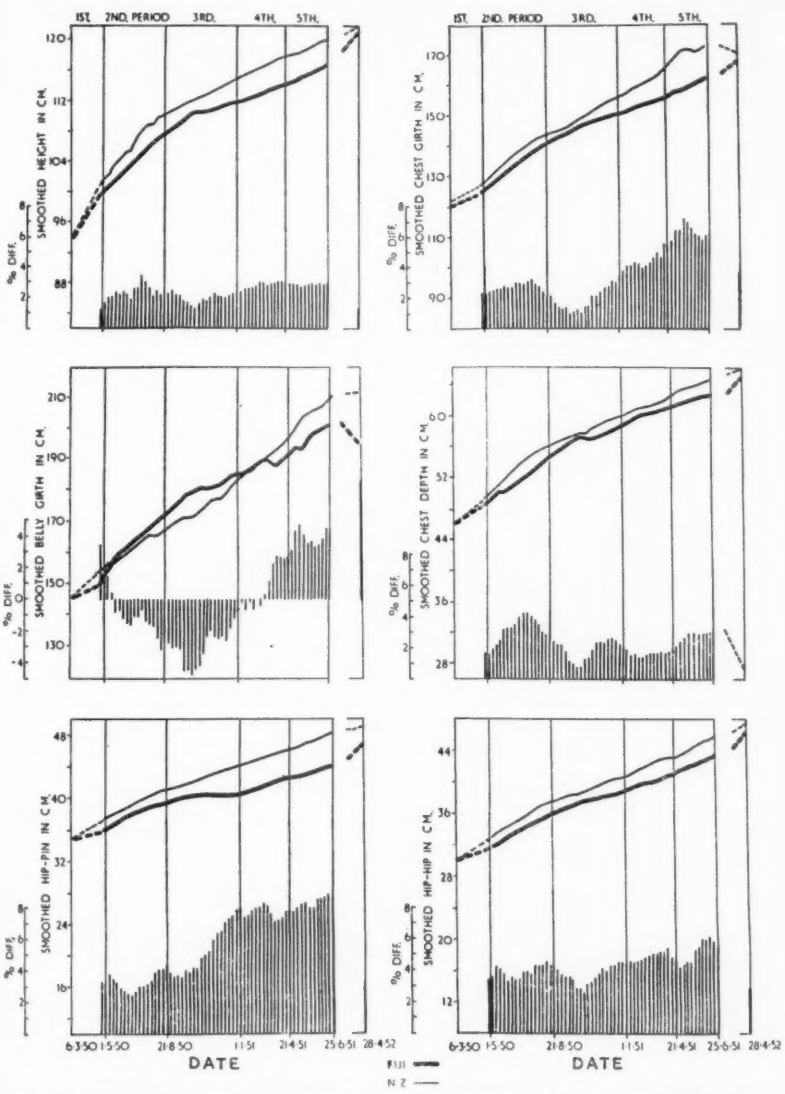

FIG. 6. Body measurements: smoothed growth curves and percentage differences between average measurements at Ruakura and at Sigatoka.

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1. *Height over withers.*—The average weekly increments in height over withers are given in Table 5. On a phase basis, the average height differences tended to become steadily greater almost up to the 2-year-old stage. However, as Fig. 6 shows, in the middle of the third phase there was an appreciable narrowing of the difference between the groups. This coincided with the relatively rapid growth of body weight in the Fiji twins. It also seems that the divergence in height was arrested in the middle of the fourth phase, despite the fact that weight differences at

TABLE 5. *Average Weekly Height Increments (cm.)*

Phase	*2*	*3*	*4*	*5*	*Total (2–5)*
New Zealand . .	8·9	4·8	3·2	2·4	5·1
Fiji	7·6	4·6	2·3	2·6	4·5
Difference . .	+1·3	+0·2	+0·9	−0·2	+0·6

this time were rapidly becoming greater. The height differences during the growing period, although small at the beginning of phases 4 to 5, and at the end of phase 5, were significant (Table 3). The average difference at the end of the first lactation, however, was approximately 1·5 cm. or 1·3 per cent., and not significant. The differences in height growth rate were never fully significant.

2. *Chest girth.*—The average weekly increments in chest girth are given in Table 6, and the average growth curves of this dimension are

TABLE 6. *Average Weekly Increments in Chest Girth (cm.)*

Phase	*2*	*3*	*4*	*5*	*Total (2–5)*
New Zealand . .	16·3	11·8	9·1	8·8	11·8
Fiji	15·7	10·4	5·1	6·6	9·9
Difference . .	+0·6	+1·4	+4·0	+2·2	+1·9

shown in Fig. 6. Because of a misunderstanding as to the correct technique, the Fiji measurements were not reliable up to the middle of the second phase.

Changes in chest girth are commonly considered to be a better indication of changes in body condition than in body growth. It is, therefore, not surprising that the fluctuations in chest girth tended to be greater than those in height. As Fig. 6 shows, after the initial check the Fiji twins almost reached the chest-girth dimensions of their New Zealand mates by the middle of the third phase, when the body weights of the two groups also converged. However, the greater belly girth (see below) of the Fiji twins at this time may automatically have caused a parallel expansion of chest girth, thus giving rather a false picture of the growth of the latter dimension. After the middle of the third phase there was a deceleration of the growth rate of chest girth in the Fiji twins, while the New Zealand twins on the contrary increased their growth rate.

Both groups continued to grow in the fourth phase at approximately the rate prevailing from the middle of the previous one, with the result that the average chest girth of the Fiji heifers in the beginning of the fifth phase was much smaller than that of their New Zealand mates. Over the first half of the fifth phase the chest girth of the New Zealand twins increased very rapidly, so that although the rate also increased in the Fiji heifers the group difference in the middle of this phase was at its maximum. From this time to the end of the phase there was a total cessation

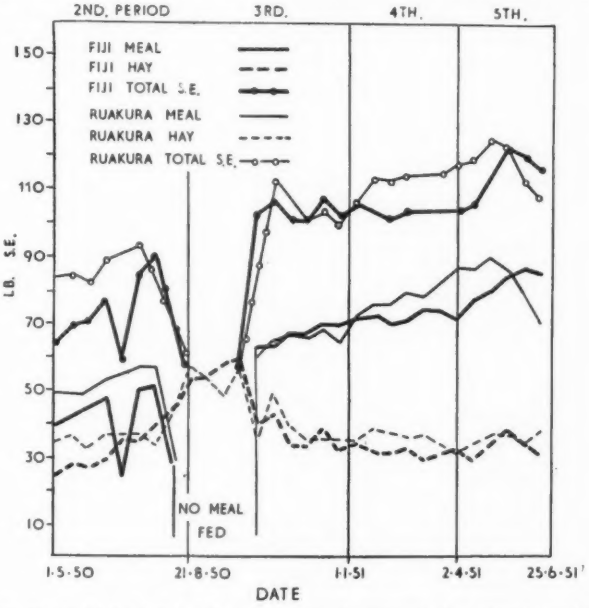

FIG. 7. Fortnightly intake of hay and meal, expressed as starch equivalent.

of chest-girth growth in the New Zealand heifers. This was apparently caused by an unaccountable sudden drop in feed intake, although the effect was not shown by the Fiji twins, whose appetite also decreased at about the same time. It remains to point out that the differences in chest girth at the end of lactation (average 6·1 cm. or 3·6 per cent.) were smaller than in the fifth phase but still significant.

3. *Belly girth.*—This (Table 7) was the only dimension studied in which the Fiji twins were at times superior. As Table 3 shows, at the end of the second phase the average belly girth of the Fiji twins was significantly greater than that of their New Zealand co-twins, and this continued throughout the third phase. A possible reason, namely the greater water intake, has already been discussed in connexion with changes in body weight. The greatest difference in favour of the Fiji heifers occurred approximately in the middle of the third phase (see Fig. 6), when an average difference of 8·5 cm. or 4·8 per cent. was recorded. However, by

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the end of this phase the differences had become small and in the middle of the fourth phase the belly-girth dimensions of the Fiji twins dropped below those of their New Zealand co-twins and remained smaller for the rest of the time. At the end of the first lactation the Fiji twins showed

TABLE 7. *Average Weekly Increments in Belly Girth (cm.)*

Phase	*2*	*3*	*4*	*5*	*Total (2–5)*
New Zealand . .	12·5	16·3	12·5	15·4	14·3
Fiji	22·7	13·4	5·1	11·1	13·6
Difference . .	−10·2	+2·9	+7·4	+4·3	+0·7

at a greater disadvantage in belly girth than in any other body measurement recorded.

4. *Chest depth.*—The average weekly increments in chest depth are given in Table 8. The differences between groups in chest depth showed

TABLE 8. *Average Weekly Increments in Chest Depth (cm.)*

Phase	*2*	*3*	*4*	*5*	*Total (2–5)*
New Zealand . .	6·7	4·0	2·3	2·6	4·1
Fiji	6·1	4·1	2·6	1·6	3·8
Difference . .	+0·6	−0·1	−0·3	+1·0	+0·3

irregular fluctuation (Fig. 6), in that peak differences occurred in the middle of the second and again at the end of the last phases. The interpretation of these fluctuations is uncertain. At the end of the lactation the difference was very small (0·54 cm. or 0·8 per cent.) and not significant (Table 3).

TABLE 9. *Average Weekly Increments in Hip-pin Distance (cm.)*

Phase	*2*	*3*	*4*	*5*	*Total (2–5)*
New Zealand . .	4·2	2·8	2·1	2·0	2·9
Fiji	3·7	1·2	1·9	1·3	2·0
Difference . .	+0·5	+1·6	+0·2	+0·7	+0·9

5. *Hip-pin distance.*—The average weekly increments in the hip-pin dimensions are given in Table 9. The difference between the groups increased throughout all five phases (Fig. 6), and attained its maximum (4·1 cm. or 8·6 per cent.) at the end of the fifth, reaching the greatest percentage difference recorded for any linear body measurement at any time. It was rather surprising that the divergence in the hip-pin measurement developed mainly during the third phase, i.e. during the time when the differences in all other measurements (including body weights) showed a tendency to narrow.

By the end of the first lactation the difference between groups was, however, small (1·6 cm. or 3·3 per cent.) although significant.

6. *Hip–hip distance.*—The average weekly increments in the hip–hip dimensions are given in Table 10. Of all measurements recorded, the hip–hip dimension showed the smallest fluctuations in growth difference between the two groups (see Fig. 6). From the time of the initial check received by the Fiji twins, i.e. from the beginning of the second phase, the differences grew slowly greater to reach their maximum at the end of the fifth phase (2·6 cm. or 5·7 per cent.). So steady was the rate of

TABLE. 10. *Average Weekly Increments in Hip–hip Distance (cm.)*

Phase	*2*	*3*	*4*	*5*	*Total (2–5)*
New Zealand . .	4·8	3·3	2·6	2·8	3·5
Fiji	4·3	3·1	2·3	2·3	3·1
Difference . .	+0·5	+0·2	+0·3	+0·5	+0·4

divergence that the growth rates were significantly different only in the fifth phase; this was due to the circumstance that the hip–hip dimension of the New Zealand twins for an unknown reason ceased growing for a short period just prior to the beginning of the fifth phase, and this was followed by an abnormally fast growth rate.

There was only a small although significant difference at the end of the first lactation (1·01 cm. or 2·4 per cent.).

Water intake.—The average 24-hour water consumption of the two groups during the third, fourth, and fifth phases is given in Table 11. As explained previously, during the second phase the results were affected

TABLE 11. *Average 24-hour Water Consumption (pints)*

Phase	*3*	*4*	*5*
New Zealand . . .	34·0	38·7	32·2
Fiji	72·1	74·3	67·7
Difference . . .	+38·1	+35·6	+35·5
Fiji as % of N.Z. . .	212	192	210

by the strangeness of the procedure, so they were discarded. The water consumption of the Fiji twins over all three periods was approximately twice as great as that of their New Zealand co-twins.

Feed intake and utilization.—The feed intake in terms of total starch equivalent (S.E.) and amount of S.E. consumed per lb. of live-weight gain, for all animals during the second, third, fourth, and fifth phases, is given in Table 12. The total fortnightly hay and meal intake is shown in Fig. 7.

The second phase was, in Fiji, one of relatively low temperatures and a consequent high growth rate. The low feed intake in both places was due to a delay in the shipment of meal from New Zealand. The result was an apparent high efficiency in terms of S.E. intake per lb. of live-weight gain, especially in the Fiji animals.

TABLE 12. *Live-weight Gain, Feed Intake (as Starch Equivalent), and Utilization*

Twin No.	2nd phase (16 wks.)			3rd phase (19 wks.)			4th phase (13 wks.)			5th phase (12 wks.)			Total of all phases (60 wks.)		
	L.W. gain lb.	*Intake lb. S.E.*	*S.E. per lb. L.W. gain*	*L.W. gain lb.*	*Intake lb. S.E.*	*S.E. per lb. L.W. gain*	*L.W. gain lb.*	*Intake lb. S.E.*	*S.E. per lb. L.W. gain*	*L.W. gain lb.*	*Intake lb. S.E.*	*S.E. per lb. L.W. gain*	*L.W. gain lb.*	*Intake lb. S.E.*	*S.E. per lb. L.W. gain*
F. 17	152	582	3·83	114	783	6·87	50	649	12·97	118	661	5·60	434	2,675	6·16
N.Z. 18	101	656	6·50	100	699	6·99	111	701	6·27	127	670	5·27	439	2,726	6·21
F. 23	150	603	4·02	90	825	9·17	31	628	20·26	84	607	7·23	355	2,663	7·50
N.Z. 24	105	678	6·46	44	724	16·45	99	630	6·37	80	628	7·84	328	2,660	8·11
F. 25	190	683	3·60	166	944	5·69	47	820	17·45	141	782	5·55	463	3,230	6·98
N.Z. 26	158	717	4·54	130	844	6·49	130	828	6·37	134	792	5·44	552	3,180	5·76
F. 29	106	611	5·77	137	832	6·07	33	690	20·92	134	721	5·38	410	2,855	6·96
N.Z. 30	157	774	4·93	131	889	6·79	106	836	7·88	150	815	5·43	544	3,314	6·09
F. 33	157	502	3·20	115	633	5·50	63	580	9·20	121	602	4·98	456	2,317	5·08
N.Z. 34	111	578	5·20	110	695	6·32	85	625	7·36	107	566	5·29	413	2,465	5·97
F. 39	129	538	4·17	143	749	5·24	45	656	14·59	106	672	6·34	423	2,615	6·18
N.Z. 40	122	643	5·27	98	711	7·25	134	686	5·12	120	701	6·84	474	2,741	5·78
F. 45	162	566	3·50	129	737	5·72	67	677	10·11	139	702	5·16	494	2,683	5·43
N.Z. 46	188	733	3·90	150	889	5·93	111	783	7·05	145	802	5·53	594	3,206	5·40
F. 47	192	624	3·25	72	853	11·85	29	686	23·66	122	702	5·75	415	2,866	6·90
N.Z. 48	156	706	4·52	138	823	5·96	101	754	7·46	102	673	6·60	497	2,956	5·95
Average:															
Fiji	155	589	3·80	128	795	6·21	46	673	14·64	120	682	5·68	448	2,738	6·11
New Zealand	137	686	5·01	113	784	6·94	110	730	6·64	121	707	5·84	480	2,907	6·06

During the third phase, meal feeding was discontinued for half of the time. The Fiji twins continued to gain in weight at a faster rate than their New Zealand co-twins, but it has been pointed out that this extra weight might well have been due to their increased water consumption, since (*a*) they failed to show the retarding effect on body weight of the discontinuance of meal feeding which was shown by the New Zealand twins, and (*b*) their linear measurements—excepting belly girth—gained more slowly than those of their co-twins. The high figure for S.E. per lb. of live-weight gain may, therefore, be a misleading one.

During the fourth phase the efficiency of S.E. per lb. of live-weight gain remained the same for the New Zealand twins but dropped drastically for the Fiji animals. It was during this time that a sharp retardation of belly-girth increment occurred in the Fiji twins.

In the fifth phase live-weight gain, S.E. intake, and therefore efficiency of S.E. per lb. of live-weight gain, were substantially the same for the two groups.

Comparison of the over-all efficiency of live-weight gain for all four phases seems to indicate that climate had little influence upon this measure. However, there is substantial reason to believe that this conclusion would be erroneous, for it has been pointed out that the high efficiency figures recorded for the Fiji animals in phases two and three were probably due to an increased water intake. Further, a comparison of efficiency figures in phase four suggests that the persistent high temperatures encountered at this time not only depressed feed intake, but were also associated with a reduced rate of gain in belly girth; this no doubt led to a distorted figure for live-weight increment so that the apparent efficiency of gain was unduly low.

Individuality.—In addition to the response in the growth rates of these twins to the direct influence of climate, the original results showed that large between-set differences in growth rate were maintained throughout the growth period. From Table 3 it is evident that the between-set differences of body weight and measurements varied in their degree of statistical significance from period to period, indicating, in effect, a marked genotype-climate interaction. In general, the four twin sets 17–18, 23–24, 25–26, and 47–48 were less adversely affected by the Fiji climate than were the remaining sets. Although the onset of high summer temperatures checked the growth of each animal, this check varied between sets not only in its degree of severity but also in its persistence.

Discussion

Within the land areas generally classified as hot and humid, the efficiency of animal production, as compared with that of more temperate regions, is of a low order. European-type cattle are usually stunted in the tropics, growth is slow, sexual maturity is delayed, and meat and milk production are consequently poor. This state of affairs may be attributed to the complex formed by the interactions of climate, nutrition, and management. Consequently any attempt to improve the situation must involve either an improvement in the environment or the breeding of

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cattle that are better suited to withstand the rigours of such an environment. The relative merits of these two lines of attack will depend upon the effective improvement per unit time that each may contribute. Thus it is of considerable importance to have basic information concerning the actual role that these major variables can play in shaping the final phenotype of the animal. The present experiment was an attempt to measure the direct influence of tropical climate, in the Sigatoka region of Fiji, on the growth of European-type cattle.

The results of this particular study demonstrated that although climate, *per se*, exerted an appreciable effect on the growth rate of European-type cattle, yet the difference in relative development between the Fiji and the New Zealand twins was surprisingly small. Just before calving, the liveweight difference amounted to only 10 per cent., this difference being reduced to 3 per cent. at the end of the first lactation. Likewise, all other measurements save belly girth showed comparatively small differences at this stage. In view of the fact that European-type cattle reared at Sigatoka are usually much more stunted and later-maturing than their contemporaries in more temperate areas, it is an obvious inference from the present results that this situation may be attributed largely to poor nutrition and/or management of the Fiji-reared animals.

Such a conclusion might, however, be questioned in view of the age of the twin calves when sent to Fiji. On arrival at Sigatoka these animals were approximately 7½ months of age. Payne reported previously that the birth weight of Friesian cattle and their weight at about 6 months of age at Sigatoka were both well below those of calves of a similar age reared in temperate zones [10]. Thus it might be argued that the detrimental effects of climate are not fully apparent unless the animals are separated at an age earlier than 6 months, because the good rearing of the calves in a temperate area for the first 6 months of life would buffer their normal response to the tropical climates. The validity of this argument is difficult to assess, because the cattle of Fiji normally calve in the cool season, when the growth check due to climate is at a minimum. Moreover, numerous workers have demonstrated that young cattle possess a marked ability to recover from an early growth check provided that the subsequent plane of nutrition is adequate [11, 12; McMeekan, unpublished information]. In this respect it is worth noting that because of the rigour of the voyage and the quarantine period, the relative development of the twins showed the greatest difference at the time of arrival at Sigatoka; the subsequent relative growth of the Fiji animals was greater than that of the New Zealand ones. While it is apparent that this element of uncertainty must be tested by further experiments, it would none the less seem reasonable to conclude from the present work that climate *per se* does not necessarily have a major limiting effect on growth, in areas comparable to Sigatoka.

The slight check to growth that was observed as a result of the direct influence of climate appeared to be a reasonably uniform one, in so far as both body condition and skeletal increment were depressed. The results for belly girth were a complicating feature of the study. The initial increase in this measurement could probably be attributed to the much

greater water consumption of the Fiji animals. However, this increment rapidly diminished with the onset of hot weather. Although the feed intake during this period was at first depressed somewhat, it rapidly recovered while the temperatures increased, but belly girth continued to show a marked depression. The fluctuation in belly girth, reflecting as it does the stomach fill, complicated the interpretation of the figures for efficiency of live-weight gain. For phase two the efficiency of gain in the Fiji animals was obviously too high because of the greatly increased water intake, whereas in phase four, when belly girth diminished, the efficiency of gain was too low. Likewise, efficiency of gain was further depressed because of the lowered intake at this period. Thus it was difficult to interpret the role that climate played in lowering the actual efficiency of live-weight gain at this stage of growth.

An interesting feature to emerge from the mass of growth data compiled in the course of this work was the change in the between-set difference of live-weight gain, which was exhibited from period to period. In effect, this change represented a marked genotype-climate interaction and indicated that there was considerable variation in the adaptability of different twins to the tropical climate. A sample of eight animals only (reduced to seven by the end of the first lactation) is too small to give precise information regarding the possibility of selecting European-type cattle capable of normal growth rates in climates such as that of Sigatoka. The results of the present experiment, however, are such as to make a selection programme appear worthy of more detailed investigation.

Summary

Eight sets of identical-twin heifer calves were divided between Fiji and New Zealand. Feeding and management in the two countries were identical, the only difference to which the animals were subjected being that of climate. The growth and milk production of the animals from the age of 7½ months to the end of their first lactation was followed in both countries. This paper deals with differences in the growth of the two groups.

Growth, feed intake, and temperature differences were recorded during five arbitrary periods or phases, from 7½ to 24 months of age, and also at the end of the first lactation.

Except for an initial setback due to transportation and quarantine, the only appreciable depression in growth rates occurred during the period when the Fiji temperatures were at their highest and the apparent efficiency of feed conversion by the Fiji animals was at its lowest. The animals were 15 months of age at the beginning of this period. The induced size difference was maintained until calving, when the average difference in weight was 84 lb. or 9·6 per cent., but by the end of the first lactation it had been substantially reduced.

The check to growth in the Fiji animals appeared to be reasonably uniform, in so far as all body measurements except belly girth were adversely affected. The increase in belly girth in the Fiji animals was attributed to greater water intake, the water intake of the Fiji twins being approximately twice that of their New Zealand mates.

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It was concluded that part only of the stunting usually apparent in European-type cattle, in the Sigatoka region of Fiji, may be attributed to the direct effect of climate.

There was evidence of a genotype-climate interaction indicating that individual European-type cattle differ in their suitability for tropical climates.

Acknowledgements

The authors are indebted to the Director of Agriculture, Fiji, for making the necessary facilities available at Sigatoka, and to the South Pacific Commission for assisting in financing the experiment. They also wish to acknowledge the assistance of the Senior Veterinary Officer, Fiji, Mr. A. F. S. Ohman, for assistance during the importation of the twins. Mr. R. Gallagher and Mr. B. Quigley undertook much of the painstaking care of the animals, while Miss G. Elliott and Peter Brumby helped considerably in the preparation of the manuscript. In statistical advice and computational work Dr. A. H. Carter and Miss J. Webster contributed appreciably. Finally the authors record their thanks to Dr. C. P. McMeekan for his continued assistance and helpful criticism.

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(*Received 14 July 1954; as revised, 29 December 1954*)

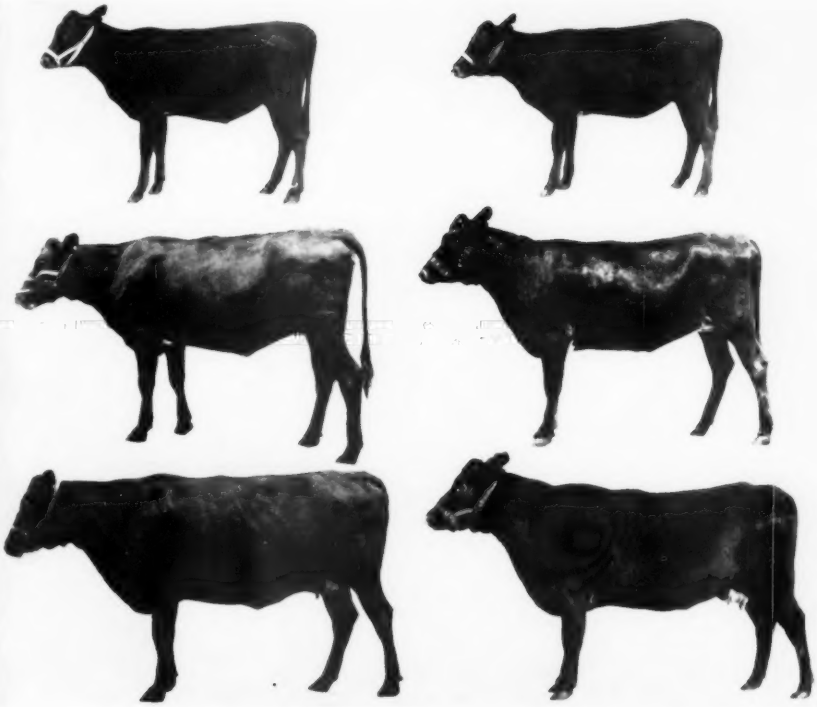

FIG. 8. Twin set Nos. 25 and 26. Fiji twin on left.

1. At separation (9 March 1950)
2. At fourth phase (5 February 1951)
3. At end of first lactation (8 July 1952)

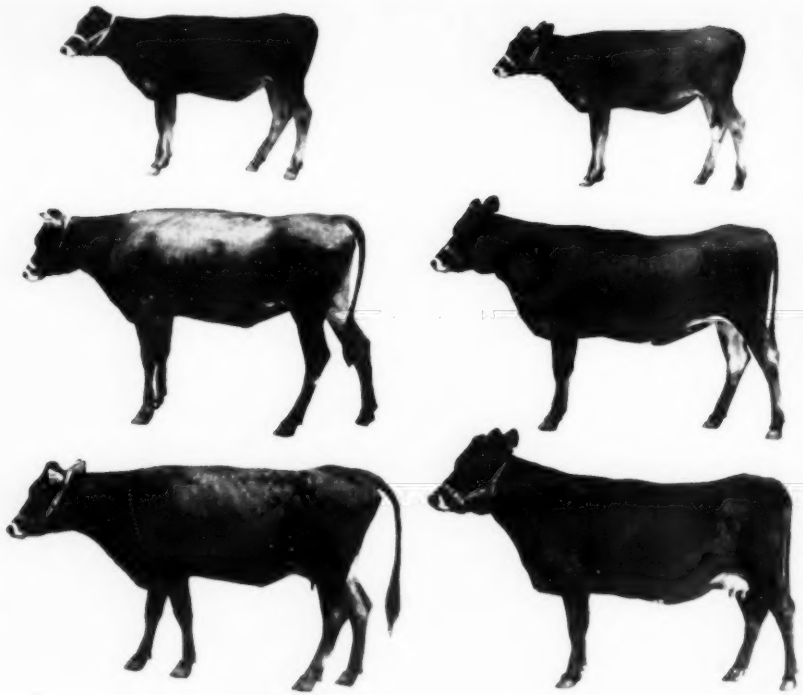

FIG. 9. Twin set Nos. 45 and 46. Fiji twin on left.

1. At separation (9 March 1950)
2. At fourth phase (5 February 1951)
3. At end of first lactation (8 July 1952)

COMPARISON OF THE AFGHAN PLOUGH AND TILLAGE PRACTICES WITH MODERN IMPLEMENTS AND METHODS

G. F. HAUSER[1]

DURING recent years, when Western countries have increasingly engaged in helping the so-called under-developed countries with the modernization of their agriculture, in order to improve the world food situation, one problem in particular has assumed widespread interest for agriculturists and soil scientists. This is the still uncertain question, whether the replacement of the local or eastern plough by modern ploughs is a matter of essential and primary importance or not.

The answers given to this question have been in many respects contradictory, and this must be so, since the effect of ploughing is dependent on such factors as the kind of soil, climatic conditions, general farming practices, the situation of the field, and water and irrigation conditions. A traditional plough developed during centuries of experience is usually quite well adapted to the local conditions, but seen with Western eyes its value is apt to be underestimated at first. Further, since the replacement of such a commonly used implement as a plough means great expense and much educational work among the farmers, it is very important to make thorough investigations under local conditions before taking steps in this direction. The first field experiments on this subject carried out in Afghanistan are described below.

Afghan ploughing and field work.—The traditional Afghan plough is a simple wooden instrument pulled by two small oxen. It only scratches and loosens the soil and does not turn it over. Every field is ploughed at least twice, once lengthwise and once across the field. The soil is loosened to a depth of 10–15 cm. (4–6 in.). Since the plough is fitted with a flat iron point 20–25 cm. broad, the weak weed roots are cut off (but not the strong ones), and a kind of plough-sole is left on top of the subsoil. If this ploughing is done properly and in suitably moist soil, the soil is crumbled somewhat more finely than after ploughing with a modern plough.

The seed-bed is further prepared by flattening the soil with a simple piece of thick timber about 1½ metres long, pulled over the field by two oxen with the farmer standing on it. The seed wheat (wheat being the most important crop of the country) is then broadcast by hand and mixed into the soil by another ploughing, after which the soil is flattened again as before.

It is obvious that this traditional method has disadvantages. First of all, the soil is not turned over and the strong weed roots are not cut off. This makes green manuring *a priori* impossible. The weed seeds are not

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[Empire Journ. of Exper. Agric., Vol. 23, No. 89, 1955]

turned under deeply enough, and they are able to germinate quickly. Secondly, the necessity of ploughing at least twice (some fields are ploughed three to five times) makes the work inefficient. Thirdly, the sowing depth is very irregular, and consequently the germination of the seed is also irregular.

The advantages of this plough are rooted in the local conditions. The fields are commonly small, mostly not exceeding ¼ to ½ acre, and very often situated in terraces made for the commonly used check-flooding irrigation. The small local plough can be turned easily and it accomplishes its work even in the many corners of these small plots. Furthermore, the soil is not moved sideways and consequently no open furrow remains at the side of the field, which would cause difficulties with irrigation. The power necessary to pull these ploughs is less than for a modern plough. And, last but not least, the Afghan plough is extremely cheap and it costs little to repair.

In order to compare the effects of the traditional and modern ploughs two field experiments were laid out. One, in the Kabul plain, an important wheat district, was planted to wheat; the other, in the sugar-beet district of Baghlan, was planted to sugar-beet.

Experimental: Wheat

A uniform piece of land of an average soil type for the Kabul plain was selected. The soil was a calcareous fine-sandy loam with a pH value of 8·5, a carbonate content of 8·1 per cent., and a humus content by Allison's method of 2·16 per cent.

The field was divided into eight plots of 130 sq. metres each. Four of the plots were planted with wheat according to the traditional method described above and the four other plots planted in the normal Western way. In this, the soil was ploughed once, 18 cm. deep, with a modern steel single-furrow plough drawn by oxen, and harrowed with a modern iron harrow. The seeds were broadcast and harrowed into the soil.

The soil was not fertilized. As seed, the selected spring wheat variety 'Regent' was chosen. In accordance with the local practice, all plots were sown at the rate of 175 kg. of seed per hectare.

Irrigation.—In the middle of May, when the rainy season had ended, two irrigations were given. By means of a measuring weir the amount of water applied to the soil was measured exactly. This check on the amount of water used was necessary because the climate is very dry and in many districts water is very limited. Thus methods consuming much water are *a priori* unfit for the country.

It was found that both treatments used practically the same amount of water, viz.: traditionally planted plots, 17·7 cm. (= 7·0 acre-inches); modern-planted plots, 17·0 cm. (= 6·7 acre-inches).

Development of plants.—It was obvious that both the germination and the first development of the plants on the modern-treated plots were more uniform than those on the traditionally planted plots. Later these visual differences disappeared, but an investigation of the roots at the beginning of June showed that in the modern-ploughed soil more fine

roots were developed in the upper 18 cm. of soil, while fewer roots penetrated to deeper soil layers, as compared with the traditionally treated soil.

Yields.—The ripening time was the same for all plots. The grain and straw yields from every plot were measured and the means and standard errors were calculated, with the results shown in Table 1.

Discussion.—The large increase in grain yield with the modern method (18·6 per cent.) and the decrease of straw yield (13·7 per cent.) were surprising. However, if we take into account that early development was promoted by the superior mixing and loosening of the soil by the modern plough, and by the shallower and more uniform sowing depth in the modern plots, the differences can be understood. The difference of the grain-straw ratios and also the better root development suggest that plant growth in the modern-treated plots was easier and of a more natural type, leading to greater grain production. This implies not only

TABLE 1. *Yield of Wheat (kg./ha.)*

	Afghan method	*Modern method*	*Difference and S.E.*
Grain	1,401	1,662	+261* ±88·6
Straw	4,921	4,247	−674* ±213
Grain-straw ratio . .	1:3·51	1:2·56	..

* Significant at P = 0·05.

a higher grain yield but also a more economical use of the plant nutrients in the soil, since the ash content of straw is higher than that of grain.

The conclusion, therefore, must be that under the given conditions (those common for the Kabul plain and most of the other wheat districts of Afghanistan) the modern combination of a soil-turning plough with a harrow will have considerable advantages over the currently used traditional implements.

In other Eastern countries there has been some evidence that the modern soil-turning plough has contributed to soil erosion. In the irrigated areas of Afghanistan, with their intensive and careful cultivation methods and skilful irrigation systems, erosion leading to the loss of cultivated fields is not to be expected.

Sugar-beet

In the Baghlan area, the sugar-beet district of Afghanistan, a similar experimental field was laid out and planted to sugar-beet. The land selected was of a soil type very common in this district, namely, a calcareous loess with a pH value of 8·6, a carbonate content of 6·4 per cent., and a humus content of 1·3 per cent. The field was very uniform. It was divided into eight plots, of 152 to 178 sq. metres each, of which four were ploughed and prepared according to the Afghan method described in the first experiment, and the other four were ploughed 20 cm. deep with a modern tractor plough and harrowed with a horse-drawn iron

harrow. The seed had to be sown by hand, since no drilling machine was available. The variety used for the experiment was the same as that sown in the whole Baghlan district: namely, the Danish 'Eagle Hill'. The plots were not fertilized.

Irrigation.—The check-flooding irrigation normally practiced by Afghan farmers was used, and the applied water was measured for each plot separately. The traditionally ploughed plots in general dried out quicker, and they therefore received three irrigations more than the modern-ploughed plots. However, the total amount of water was nearly the same for both series, viz.: traditionally treated plots, total, 95·2 cm. (= 31·3 acre-inches) in sixteen irrigations; modern-treated plots, total, 94·1 cm. (= 30.9 acre-inches) in thirteen irrigations.

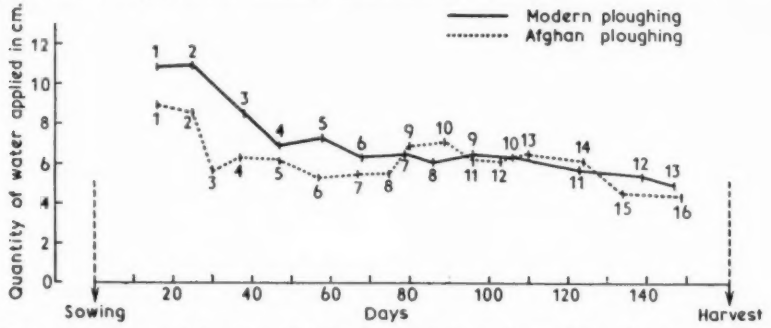

FIG. 1. Number and duration of irrigation periods, and quantities of water applied: sugar-beet experiment.

In Fig. 1 the irrigation periods and the amounts of water per irrigation are shown for both series. It is evident that the modern-ploughed and more deeply loosened soil took up more water, especially during the first period, and stored this water better, than did the soil of the traditionally treated plots. Consequently the intervals between irrigation were longer on the modern plots, and this was a considerable advantage for hoeing.

Field work and plant development.—The beet seed was sown in flat soil, at a row distance of 45 cm. The germination was very uniform and was the same in both series. Each of the three hoeings was done with common hand hoes two or three days after an irrigation, depending on the moisture status of the soil.

A difference in leaf development between the two series appeared after the first third of the growing period, in favour of the modern-ploughed plots. But it was only small and it disappeared after the second third of the growing period. By this time the root development was much stronger in the modern-ploughed plots. The time of ripening was the same for both series.

Yields.—The roots of every plot were weighed and their sugar content was determined. In Table 2 the means of the four replicates and their standard errors are given.

Discussion.—The differences between the two treatments were 23 per

cent. for the root yield and 27 per cent. for the sugar yield, in favour of the modern plough. The soil of this experiment field, which was of the type common in the Baghlan area and very frequently found in the whole north of Afghanistan, was a loess that becomes very hard and compact when dry. The Afghan plough could not go deeper than 12 cm., leaving the subsoil in its original compactness, while the modern plough loosened the soil down to 20 cm. Consequently the beets on the traditionally ploughed plots were short and not well shaped, while those of the modern series had a long, slender shape which caused a higher yield and also a higher sugar content.

It is evident that in sugar-beet cultivation as well as in wheat cultivation the modern plough has great advantages over the Afghan plough. It can loosen the soil to the depth necessary for sugar-beet in a single operation. With the native plough each field must be ploughed at least twice if not more, and even then the result can never be the same as with the modern plough because of the shallow ploughing depth.

TABLE 2. *Yields of Sugar-beet and Sugar (metric tons per ha.)*

	Weight of roots	*Sugar content*	*Sugar yield*
		%	
Modern plough . .	27·8*	17·4	4·86*
Afghan plough . .	22·6	16·9	3·82
S.E. ± . . .	1·44	..	0·266

* Difference significant at P = 0·05.

General conversion to modern cultivation methods would involve a national financial problem, but both experiments show that, this apart, under Afghan conditions the introduction of a soil-turning plough (even of the simplest construction), combined with a harrow, would lead to an increase of the country's agricultural production. It would lead also to saving of the farmer's working time, a factor which, because of an existing labour shortage, is of great importance in some districts of Afghanistan.

Summary

Two field experiments were carried out, one with wheat in the Kabul district and one with sugar-beet in the Baghlan district (northern Afghanistan), in order to compare modern cultivation methods with the traditional ones, which are described. The applied irrigation water was measured in both experiments, since water is a limiting factor in large parts of the Afghan agricultural area.

The results of the wheat experiment showed an increase in grain yield of 18·6 per cent. in favour of the modern steel plough and harrow, while the straw production on the modern-treated plots was 13·7 per cent. less than that on the traditionally treated plots. The irrigation water required was the same with both methods of cultivation.

The experiment on sugar-beet also showed yield increases in favour of the modern plough: namely, 23 per cent. for the root yield and 27 per

cent. for the sugar yield. The ploughing depth of the Afghan plough, restricted to 12–15 cm., was not sufficiently deep for sugar-beet, especially in the hard Baghlan soils. The modern plough, turning the soil 20 cm. deep, permitted better development and longer shape of the beets, which resulted in higher yield and sugar content.

The irrigation measurements in this experiment showed that the modern-ploughed fields stored the water more effectively, so that fewer but heavier irrigations could be applied on the modern plots than on those traditionally cultivated. This facilitated the hoeing and cleaning work in the field and increased its effectiveness.

(*Received 29 December 1954*)

THE COMPOSITION AND NUTRITIVE VALUE OF CERTAIN FEEDINGSTUFFS IN NIGERIA
I. ROOTS, TUBERS, AND GREEN LEAVES

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THERE are well over eight million head of cattle and about that number each of sheep and goats in Nigeria [1]. To these should be added a large and rapidly increasing population of pigs, a not insignificant number of donkeys, asses, horses, and camels, and a large number of chickens, ducks, turkeys, guinea-fowl, and other domestic birds. Meat, in which there is a big internal trade, is an important item of diet and the main source of animal proteins for the people of Nigeria. It is estimated that about one million cattle and six million sheep and goats are slaughtered annually for this purpose [2]. There is, in addition, a valuable export trade in hides and skins, amounting in 1951 to over 12,000 tons worth about eight million pounds, or nearly one-sixteenth of the value of the country's total exports for that year.

Nigeria is capable of increasing her present livestock population many times, provided that improved methods of feeding, breeding, and disease control can be adopted and planning brought to bear on her national production of livestock. There are vast undeveloped tracts of potentially good cattle land, particularly in the northern parts of the country, and the land is suitable for cultivating a large variety of feedingstuffs, the qualities and nutritive values of most of which remain to be ascertained.

One of the main obstacles to livestock improvement in the country is inadequate and unbalanced feeding. The situation was well summed up by Shaw and Colville [1], who wrote, 'The basic problem concerning any livestock improvement in Nigeria is not one in the first instance for the geneticist, but for the animal feeder. It is the nutrition of the existing breeds of cattle, sheep, and goats that has first to be put on a higher plane before the geneticist and animal breeder can either select or improve.' The majority of the livestock in Nigeria, with the exception of some of those at Government and University College experimental farms, are reared on very low planes of nutrition.

In both the north and the south, but particularly in the former where the vast majority of the Nigerian livestock are found, cattle, sheep, and goats live on coarse, bush grazing of the savannah land during the rainy season; this is sometimes limited to four or five months of the year in the more northerly parts of the country. For the rest of the year, with lack of adequate supplementary feeding, cattle have to subsist on very poor-quality grass when and where available. The result is a prolonged period of malnutrition, feeding being often at near-starvation levels. Indeed, at no time of the year do Nigerian cattle receive really adequate nutrition. In consequence the development of the animals is slow and

[Empire Journ. of Exper. Agric., Vol. 23, No. 90, 1955]

badly proportioned. It takes 3 to 4 years, for instance, for cattle to reach sexual maturity [3], and the matured animal is not uniform in conformation since this is largely determined by the state of nutrition.

Progress in nutritional work with a view to the improvement of West African livestock has been hindered by a lack of knowledge of the chemical constituents of the feedingstuffs grown locally. As far as can be ascertained, the only systematic work on the subject was that presented by Hartley and Ross [4] to the Third West African Agricultural Conference in 1938, on some of the feedingstuffs of northern Nigeria, incorporating the information available on the subject previous to that time. Apart from dried leaves and hays of cereals and pulses, this study was very limited in scope. Subsequent, unpublished, information exists in the files of the Government Department of Agriculture in Nigeria (private communication): it would seem to have accrued as a result of unco-ordinated analyses of various materials sent to the Agricultural Chemist from the field stations scattered over the country. A few of the earlier analyses of samples from Nigeria, carried out at the Imperial Institute, London, have been published by the Commonwealth Bureau of Animal Nutrition [5]. Information obtained from similar work abroad could only serve temporarily as a guide; it is inadequate for the accurate calculation of rations, since the interactions of climate, soil, nutrition, species, and other factors must cause appreciable differences in chemical composition between locally grown feedingstuffs and those grown abroad under different climatic conditions.

Experimental

Most of the material for the present investigation was obtained from the Crop Collection Plot of the Faculty of Agriculture Farm, University College, Ibadan. The Plot was originally established in 1950 to raise seeds of crops grown in various parts of Nigeria, for botanical and other studies. Samples were taken in February and March 1953 from crops harvested from the Plot during October to December 1952. Some of the material studied, particularly the yams and other tubers, was bought from the local market in Ibadan town. Samples were procured at about the same time as the corresponding samples from the College farm were collected, and they were generally in similar states of drying.

Investigations at the time of purchase showed that the yams came mainly from Ibadan and Oyo Provinces and from Ekiti Division of Ondo Province, all within a radius of some 75 to 100 miles of Ibadan. A few of the feedingstuffs, namely Telfairia and sweet cassava, were obtained from local farms around Ibadan. All the feedingstuffs analysed, therefore, were grown in the south-western part of Nigeria.

The soil of the Crop Collection Plot is slightly on the acid side of neutrality, with a pH up to 6·8. It is deficient in phosphorus and somewhat deficient in nitrogen, but contains adequate amounts of available potassium. The Plot received no fertilizer treatment before or during the growing of the crops. In this and other respects the soil was, in general, typical of the crop-raising soils of the area.

Samples were conveyed to the laboratory and dried almost immediately. With the roots and tubers the bark or peel was removed for separate analysis, peeling being carefully done with a pen-knife in the same way that yams and cassava are prepared for cooking. Sub-samples were then taken from such preparations for the determination of fresh moisture content. The remainder was spread evenly on paper-covered trays and dried in a vacuum hot-air circulating oven at about 60° C., a temperature at which no overheating occurred but which is known to be high enough to put a check to enzymic and respiratory action. Drying was usually completed within 24 hrs. The samples were then ground in a Christy-Norris hammer mill, using a $\frac{1}{32}$-in. sieve, and stored in airtight screw-capped bottles until analysed.

The average chemical composition of the feedingstuffs (as shown in the columns headed 'A', Table 1) was determined in the Animal Nutrition laboratory of the Faculty of Agriculture. The samples were analysed in duplicate by the usual conventional methods for residual moisture, crude and true protein, ether extract (oil and fat), crude fibre, total ash, and silica. From the last two determinations, the silica-free ash was obtained by difference. The figures for nitrogen-free extractives (soluble carbohydrate) were arrived at by difference, deducting from one hundred the sum of the crude protein, crude fibre, ether extract, and total ash.

Except for digestible proteins, the figures for the digestible nutrients in the 'B' columns of Table 2 were calculated from those in the 'A' columns of Table 1 by using the digestibility coefficients of Morrison [6] and of Schneider [7], preferably the former. The resulting digestible-nutrient values are sufficiently reliable for calculating rations for livestock feeding in Nigeria, at least until facilities become available in this country for comprehensive digestibility trials with cattle, sheep, and pigs.

The digestible crude and true protein of the roots and tubers, on the other hand, was determined directly by the method originally devised by Stutzer, the material being incubated at 37° C. for 48 hrs. with best commercial scale pepsin in an acid medium. The procedure described by Knowles and Watkin [8] was adopted. This method was used since protein digestibility-coefficient figures for most of the roots and tubers have not been published. Figures obtained by such methods agree quite well with the results of digestion trials obtained by animal experiments [8].

The last columns, headed 'C', of Table 2 record the nutritive ratio, the protein equivalent, the starch equivalent, and the total digestible nutrients, all calculated from the digestible nutrients in the 'B' columns. The 'V' values, taken from Woodman's Tables [9], were used in order to arrive at the starch-equivalent figures.

The nutritive ratio measures the proportion of the digestible proteins, expressed as unity, to the digestible energy constituents, principally carbohydrates, fibre, and fats (ether extract $\times 2{\cdot}3$).

The protein equivalent was derived from the arithmetic mean of the digestible crude and true protein values. In spite of recent objections by Maynard [10] to its application, the protein-equivalent figure is still employed in calculating rations for livestock since it makes an allowance

TABLE 1. *Composition of Feedingstuffs in Nigeria*

No.	Feedingstuff: Common name	Feedingstuff: Scientific name	A: Dry matter	Crude protein	True protein	Ether extract	Crude fibre	Nitrogen free extractives	Total ash	Silica free ash
	ROOTS, TUBERS, AND GREEN LEAVES		%	%	%	%	%	%	%	%
1	Cassava (Manioc) root, unpeeled (bitter var.)	*Manihot utilissima*	31·94	2·71	1·68	0·53	3·09	91·01	2·66	2·41
2	Cassava root, peeled	,, ,,	28·50	2·58	2·58	0·46	0·43	94·12	2·41	2·29
3	Cassava root, peel only	,, ,,	27·94	5·29	4·57	1·18	20·97	66·63	5·93	4·60
4	Cassava root, unpeeled (sweet var.)	,, ,,	31·94	2·38	1·30	0·65	1·95	92·13	2·89	2·73
5	Sweet cassava root, peeled	,, ,,	28·50	1·66	1·66	0·65	1·60	90·86	5·23	4·96
6	Sweet cassava root, peel only	,, ,,	27·94	5·61	2·37	1·39	10·31	78·25	4·44	3·83
7	Cassava leaves	,, ,,	25·60	14·69	13·76	8·39	15·63	45·22	16·07	7·87
8	Cassava flour (Gari)	,, ,,	86·47	1·20	1·02	0·38	2·31	94·03	2·08	0·92
9	Coco-yam (Tannia) tuber, unpeeled	*Xanthosoma sagittifolium*	24·89	7·85	6·33	0·70	1·93	84·30	5·22	4·96
10	Coco-yam (Tannia) tuber, peeled, edible portion	,, ,,	21·92	5·87	4·93	0·59	1·24	88·46	3·84	3·64
11	Coco-yam (Tannia) tuber, peel only	,, ,,	33·18	9·40	7·75	0·75	5·72	75·32	8·81	7·83
12	Coco-yam (Tannia) leaves	,, ,,	9·43	20·62	17·15	11·74	12·05	43·41	12·18	11·12
13	Coco-yam (Taro) tuber, unpeeled	*Colocasia esculenta*	26·52	8·66	6·90	0·71	2·38	83·42	4·83	2·79
14	Coco-yam (Taro) tuber, peeled	,, ,,	27·77	7·57	6·30	0·37	1·63	85·69	4·74	2·69
15	Coco-yam (Taro) tuber, peel only	,, ,,	17·62	9·56	7·01	2·05	32·02	37·89	12·17	11·06
16	Coco-yam (Taro) leaves	,, ,,	8·23	24·95	22·53	10·66	12·08	39·89	12·42	11·31
17	Sugar-cane leaves	*Saccharum officinarum*	22·48	7·89	6·63	3·38	13·28	66·43	9·02	7·97

17	Sugar-cane leaves	*Saccharum officinarum*	22·48	7·89	6·63	3·38	13·28	66·43	9·02	7·97
18	Sweet potato tuber, unpeeled	*Ipomoea batatas*	28·08	5·36	4·05	0·54	0·33	90·56	3·21	3·15
19	Sweet potato tuber, peeled	,, ,,	28·72	5·24	3·81	0·46	0·14	91·49	2·67	2·60
20	Sweet potato tuber, peel only	,, ,,	11·73	6·33	5·73	1·34	0·34	87·44	4·55	4·18
21	Sweet potato, young leaves	,, ,,	12·45	24·65	22·58	3·58	9·10	51·20	11·47	9·48
22	Talinum leaves (green)	*Talinum triangulare*	9·68	21·09	14·99	1·47	10·34	32·54	34·56	33·49
23	Telfairia leaves (green)	*Telfairia occidentalis*	13·63	21·17	18·58	12·94	12·79	39·24	13·86	12·78
24	Yam, Chinese, tuber, unpeeled	*Dioscorea esculenta*	18·62	8·73	5·78	0·54	3·45	83·08	4·20	3·97
25	Yam, Chinese, tuber, peeled	,, ,,	18·85	7·73	4·84	0·05	0·95	88·62	2·65	2·42
26	Yam, Chinese, tuber, peel only	,, ,,	7·03	9·99	7·33	0·86	7·59	75·29	6·27	5·66
27	Yam, trifoliate, tuber, unpeeled	*Dioscorea dumetorum*	21·36	12·58	6·95	1·31	1·39	81·34	3·38	2·68
28	Yam, trifoliate, tuber, peeled	,, ,,	16·35	11·73	6·10	1·21	1·02	83·36	2·68	2·35
29	Yam, trifoliate, tuber, peel only	,, ,,	11·96	16·13	10·94	1·94	8·30	63·32	10·31	4·33
30	Yam, water, tuber, unpeeled	*Dioscorea alata*	34·15	8·10	7·17	0·82	2·59	83·33	5·16	4·96
31	Yam, water, tuber, peeled	,, ,,	26·17	7·26	6·68	0·58	2·29	84·71	5·16	4·99
32	Yam, water, tuber, peel only	,, ,,	25·87	11·73	9·98	1·01	6·56	71·20	9·50	6·75
33	Yam, white, tuber, unpeeled	*Dioscorea rotundata*	26·17	5·87	4·23	0·46	2·38	87·92	4·30	4·24
34	Yam, white, tuber, peeled	,, ,,	24·10	4·42	3·75	0·34	1·48	90·11	2·75	2·51
35	Yam, white, tuber, peel only	,, ,,	17·10	11·21	8·82	1·17	9·47	68·40	9·76	7·37
36	Yam, yellow, tuber, unpeeled	*Dioscorea cayenensis*	16·60	6·15	5·41	0·39	2·44	87·82	3·20	2·93
37	Yam, yellow, tuber, peeled	,, ,,	16·10	5·44	4·95	0·17	0·77	90·60	3·03	2·57
38	Yam, yellow, tuber, peel only	,, ,,	21·70	7·42	6·56	0·65	7·61	76·84	7·48	6·17

TABLE 2. *Calculated Nutritive Values of Feedingstuffs in Nigeria*

No.	Feedingstuff / Common name	B Calculated digestible nutrients Per cent. of dry matter: Digestible crude protein	Digestible true protein	Digestible ether extract	Digestible fibre	Digestible nitrogen free extractives	C Calculated from digestible nutrients: Nutritive ratio	'V' Correction factor	Per 100 lb. of food: Protein equivalent	Starch equivalent	Total digestible nutrient
	ROOTS, TUBERS, AND GREEN LEAVES	%	%	%	%	%	1:	%			
1	Cassava (Manioc) root, unpeeled bitter var.)	1·73	0·98	0·28	1·19	77·36	45·76	..	0·43	..	25·84
2	Cassava root, peeled	1·99	1·76	0·24	0·25	80·00	40·60	..	0·54	..	23·59
3	Cassava root, peel only	1·98	1·50	..	..	..	..	..	0·49	..	..
4	Cassava root, unpeeled (sweet var.)	1·66	0·70	0·34	1·11	78·31	48·31	..	0·38	..	26·14
5	Sweet cassava root, peeled	1·37	1·18	0·34	0·91	77·23	57·61	..	0·36	..	22·88
6	Sweet cassava root, peel only	3·59	2·92	..	..	..	..	..	0·91	..	..
7	Cassava leaves	..	..	..	..	..	..	..	..	..	..
8	Cassava flour (Gari)	..	..	..	..	..	..	..	..	..	..
9	Coco-yam (Tannia) tuber, unpeeled	6·56	5·16	0·39	−1·02	78·40	11·93	100	1·46	20·98	21·11
10	Coco-yam (Tannia) tuber, peeled, edible portion	5·04	4·34	0·32	−0·66	82·27	16·34	100	1·03	19·06	19·15
11	Coco-yam (Tannia) tuber, peel only	6·93	5·47	0·29	−0·80	70·05	10·09	78	2·06	19·75	25·49
12	Coco-yam (Tannia) leaves	14·23	11·83	5·17	9·76	37·77	4·18	..	1·23	..	6·92
13	Coco-yam (Taro) tuber, unpeeled	7·29	5·65	0·39	−1·26	77·58	10·59	100	1·72	22·26	22·41
14	Coco-yam (Taro) tuber, peeled	6·88	6·37	0·20	−0·86	79·69	11·52	100	1·84	23·79	23·93
15	Coco-yam (Taro) tuber, peel only	3·39	1·33	0·14	−0·23	35·24	20·91	78	0·42	6·78	6·82
16	Coco-yam (Taro) leaves	17·22	15·55	4·69	9·78	34·70	3·21	..	1·35	..	5·95

17	Sugar-cane leaves	4·26	3·58	1·79	7·97	35·87	11·26	..	0·88	..	12·12
18	Sweet potato tuber, unpeeled	4·64	2·20	0·30	0·17	84·22	18·34	100	0·96	25·08	25·19
19	Sweet potato tuber, peeled	4·76	3·33	0·25	0·07	85·09	18·01	100	1·16	25·88	25·99
20	Sweet potato tuber, peel only	4·42	3·88	0·52	0·05	81·32	18·68	78	0·49	7·92	10·20
21	Sweet potato, young leaves	9·61	8·81	2·00	5·55	29·18	4·09	..	1·15	..	6·10
22	Talinum leaves (green)	..	..	..	..	..	..	..	..	..	..
23	Telfairia leaves (green)	14·61	12·82	5·69	10·36	34·14	3·94	..	1·87	..	9·80
24	Yam, Chinese, tuber, unpeeled	8·02	5·19	0·30	−1·83	77·26	9·49	100	1·23	15·56	15·67
25	Yam, Chinese, tuber, peeled	7·25	4·48	0·03	−0·50	82·42	11·31	100	1·11	16·74	16·82
26	Yam, Chinese, tuber, peel only	8·81	6·56	0·34	−1·06	70·01	7·91	78	0·54	4·27	5·52
27	Yam, trifoliate, tuber, unpeeled	11·91	6·28	0·72	−0·74	77·52	6·65	100	1·94	19·09	19·29
28	Yam, trifoliate, tuber, peeled	11·02	5·63	0·67	−0·54	58·89	5·48	100	1·36	11·44	11·59
29	Yam, trifoliate, tuber, peel only	14·67	9·82	0·76	−1·16	68·19	4·69	78	1·47	7·67	9·98
30	Yam, water, tuber, unpeeled	4·86	4·62	0·45	−1·37	77·50	15·88	100	1·62	27·85	28·00
31	Yam, water, tuber, peeled	5·30	5·07	0·32	−1·21	78·78	14·78	100	1·36	21·76	21·88
32	Yam, water, tuber, peel only	7·20	6·15	0·39	−0·92	66·22	9·19	78	1·73	14·69	18·98
33	Yam, white, tuber, unpeeled	4·82	3·52	0·25	−1·26	81·77	16·82	100	1·09	22·38	22·48
34	Yam, white, tuber, peeled	3·68	3·26	0·19	−0·77	83·10	22·49	100	0·84	20·76	20·83
35	Yam, white, tuber, peel only	8·94	6·91	0·46	−1·33	63·61	7·09	78	1·40	9·88	12·72
36	Yam, yellow, tuber, unpeeled	4·42	2·96	0·21	−1·29	81·67	18·29	100	0·61	14·10	14·15
37	Yam, yellow, tuber, peeled	4·20	3·46	0·09	−0·40	84·26	20·00	100	0·62	14·16	14·21
38	Yam, yellow, tuber, peel only	4·72	3·08	0·25	−1·07	71·46	15·04	78	0·85	12·81	16·42

for the water-soluble 'amides', which may not possess the full nutritive value of the 'true' or pure proteins. This method is particularly useful when livestock are fed on roots, tubers, and other succulent feeding-stuffs which may possess high percentages of 'amides'. For a fairly large number of the feedingstuffs dealt with in these tables the quality of the nitrogenous substances is unknown; but it is worth noting that the differences between the crude and true proteins in some of them, particularly the yam varieties and Bambara groundnut, were considerable.

The 'V' values: these, which represent the percentage availability, were taken from Woodman's tables [9] for the various feedingstuffs. With sweet potatoes, coco-yams, yams, and their peelings, the factors for potatoes and potato haulms were applied, as these were considered to be the nearest substitutes possible. The starch-equivalent figures were calculated by using methods originally described by Kellner [11], employing the 'V' values where they were available.

The total digestible nutrient (TDN) figures are a valuable guide in the feeding of swine and other non-ruminant animals, to which the starch-equivalent figures may not be strictly applicable. In addition, these figures serve a useful purpose where the 'V' values are not available for the calculation of starch equivalents. Where both the starch equivalent and the total digestible nutrient figures were calculable, the actual differences between the two were usually small, even though the former proved consistently higher than the latter.

Results and Discussion

The results of analysis of the samples, and the values derived from them, are shown in Tables 1 and 2. With regard to the proximate constitutents, it is worthy of note that cassava roots showed well-marked differences from the various tubers. Thus the crude-protein contents of cassava root, and of its flour product 'gari', were markedly low when compared with those of yam, coco-yam, and sweet potato. Of the yam varieties, trifoliate yam possessed the highest amount of crude protein, with consequently a relatively narrow nutritive ratio (average, 1:5·6), while the white yam had the widest ratio of all those analysed.

The water yam was relatively higher in its mineral content than any of the other roots and tubers investigated, whereas cassava was poor in this constituent. All the roots and tubers agreed in having higher concentrations of protein, ash, oil, and, of course, crude fibre in their peels than in the edible portion. Conversely, these peels were lower in their content of nitrogen-free extractives than was the edible part.

Along with its low content of protein and ash, cassava was high in nitrogen-free extractives, being one of the highest materials in this respect. It possessed the widest nutritive ratio of all roots and tubers analysed. Its total digestible nutrient figures—closely related to starch equivalent—also ranked among the highest of the roots and tubers.

The leaves of these roots and tubers are valuable sources of protein and minerals, sweet potato and coco-yam leaves being higher than those

of cassava. Talinum leaves were conspicuously rich in ash: much more so than those of the fluted pumpkin, although the latter leaves were higher in their content of true protein than the former.

Manihot utilissima Pohl.—Cassava belongs to the natural order Euphorbiaceae. The plant is so well known in the tropics that it need not be described. The cultivation of cassava is predominantly confined to the humid tropics, and the 25th parallels may be said to limit its satisfactory growth. It cannot stand much cold; in India the cold weather of November and December tends to make it shed its leaves and causes its roots to become soft and to lose quality [12]. It thrives from sea-level up to an elevation of some 3,500 ft.

The value of cassava lies not so much in its nutritive value, which, apart from its starch content, is low, as in its ease of propagation from cuttings and its economy of production, for it requires comparatively little weeding during its period of growth. It yields from 4 to 12 tons or more per acre, and is one of the most productive root crops in the tropics in terms of dry matter per acre.

Cassava is widely used in West Africa as a cheap and valuable source of carbohydrates for both man and livestock. For human consumption it can either be peeled, cooked, and taken as a vegetable, or grated, fermented, and roasted as flour and eaten as 'gari'—the form in which it is more usually taken by man in Nigeria. 'Sweet' varieties are commonly used in the former way, and 'bitter' varieties in the latter. Cassava contains a cyanogenetic glucoside, linamarin, which in the 'sweet' varieties is chiefly confined to the cortex, whereas it is more evenly distributed through the root of the 'bitter' varieties [13]; the methods of preparation described protect the consumer against the danger of hydrocyanic poisoning.

The value of cassava for domestic animals is well recognized in actual livestock feeding in Nigeria, where it is given either fresh or cooked to sheep, goats, pigs, and quite often to cattle. In areas of high cassava production, where 'gari' or 'fufu' (dried cassava flour) constitute the staple starchy food for man, the peel of cassava usually forms the main, and perhaps the only, food for domestic sheep and goats. It is highly palatable and well sought after by these animals. In the United States of America also, where only the sweet varieties are grown, cassava is fed as a good source of carbohydrate, when adequately balanced with protein, to dairy and fattening cattle, horses, hogs, and poultry.

The present work confirms that Manihot is a valuable source of starch, being richer in easily digestible carbohydrate than most of the other tropical roots and tubers. Although starch equivalents were not determined for cassava, its total digestible nutrient contents were among the highest for any material studied, and as pointed out earlier, these values are close to those for starch equivalent. Since cassava is so highly palatable to livestock, and is cheaply produced even on relatively poor soils, it is a promising source of cheap carbohydrate in Nigeria. Manihot was, however, remarkably poor in protein and it was somewhat low in ash. It therefore possessed an unusually wide nutritive ratio, even for a root. Feeding whole cassava would seem advisable only when

it is balanced with a protein-rich concentrate adequately supplemented by mineral and vitamin foods.

Like that of most roots and tubers, cassava peel was richer than the edible portion in protein, ether extract, and ash. This part of the root is a useful waste product in the feeding of sheep, goats, and cattle in areas of high cassava production, particularly when the varieties are low in hydrocyanic acid.

Cassava leaves were considerably richer than any other part of the plant in protein, oil, and ash, and were fairly good in carbohydrates. They are well relished by stock. The leaves are thus a valuable feeding-stuff and, when fresh, they are capable of serving as protein supplements for ruminants and even pigs. They are also good as fodder when dry, although they crumble very readily.

'Gari', the dried flour, was low in protein, oil, ash, and crude fibre, but rich in carbohydrates. Since 'gari' is free from hydrocyanic acid, it is a valuable source of energy in the rations of livestock, particularly during the dry season. It can be fed to all classes of livestock and is particularly suitable for swine and poultry. Because it is almost wholly a starchy food, however, a fair amount of protein and vitamin-rich concentrates is required to balance it.

Xanthosoma sagittifolium Schott. (Tania coco-yam); *Colocasia esculentum* Schott. (Taro coco-yam).—Xanthosoma, which was more recently introduced to the West Coast of Africa, from the West Indian islands, seems to be the more productive of the two types of coco-yam. It is gradually replacing Colocasia, which was said to have found its way earlier from India and the Pacific Islands through Egypt to this part of the world. The leaf of Xanthosoma is sagittate in shape and dark green in colour, with its basal lobes unjoined, in contrast to the peltate-shaped, pale-green leaf of Colocasia, the lobes of which are joined at the base. Both types grow to a height of from 4 to 6 ft., and possess very large leaves. They produce corms, a large corm being surrounded by smaller ones (cormels), and all of them usually contain good-quality carbohydrate which is valued as food for both man and beast. The cormels are more commonly used than the corms as a vegetable for human consumption.

The tubers of these plants were next only to certain of the yam varieties in their high content of crude and true protein; they were exceptionally rich in ash and low in fibre, and formed fair sources of oil and fat. Taro seemed slightly superior to tania in its content of crude and true protein, although the latter was richer in mineral elements.

Most of the non-starchy nutrients of these plants were concentrated in the outer peel of the corms, which contained a fairly high proportion of crude and pure protein, and of total and silica-free ash, and was richer in oil than the carbohydrate-rich fleshy portion. The peel is thus a valuable feed for ruminants and should not be discarded as waste.

Cattle, sheep, and goats are fond of coco-yam leaves, which is explained by their chemical constitution. In both types, the crude- and pure-protein content, the oil and fat, and the ash were exceptionally high for root crops; indeed, the leaves compared favourably with good pasture

from well-cultivated leys. The leaf of taro was consistently higher than that of tania in all the nutrients except oils. The high percentage of ash in these leaves is probably responsible for their high palatability to livestock. Since the leaves of these coco-yams are free from alkaloids and cyanogenetic glycosides, they can provide a useful fodder for both ruminants and horses. The young leaves of both types of coco-yam are eaten like spinach on the West Coast, and as a vegetable they are a valuable source of minerals and vitamins [14].

Although not so used at present, coco-yam tubers could form a cheap and useful source of nutrients for pigs. They would need cooking for this purpose, since they contain an acrid substance which is irritating to the digestive tract and may even prove poisonous. This substance is removed by cooking, which also renders the starch more digestible.

Ipomoea batatas Poir. (Sweet potato).—Believed to have been spread all over the world by the western European explorers, the sweet potato is now grown extensively in tropical and sub-tropical countries and it forms one of the subsidiary food plants in many parts of southern Nigeria.

It is a sun-loving plant, requiring a growing period of at least four months of warm weather. Slight frost kills its foliage and prolonged exposure of the plant to low temperatures is damaging. The sweet potato is a herbaceous climber; variations in the leaves, in the manner of growth of the plant, and in the yield, colour, size, and shape of the tubers and their storage qualities, give rise to the many cultivated varieties of the plant.

The young foliage leaves of the sweet potato serve as a good green vegetable for man and are highly relished by cattle, sheep, and goats. Analysis of the young leaves (Table 1) showed that they were rich in protein, ash, and oil, although somewhat high also in crude fibre. They have been reported to be rich in calcium [15]. When regularly cut, the leaves form a valuable fodder of high nutritive value. Frequent cutting of the foliage, however, tends to reduce the yield of the tubers.

The vines of the sweet potato form a useful dry forage crop for ruminants, and since they last throughout the dry season they are of value for supplementary feeding during that period when grazing is scarce. They contribute to the maintenance and also the production rations of ruminating animals.

It will be noted from the Tables that sweet potato tuber is a valuable source of nutrients because, in addition to being rich in carbohydrates, it contained moderate amounts of crude protein and of silica-free ash, while it had a low fibre content. The carbohydrates of sweet potato are highly digestible, since they consist predominantly of starch along with 4 to 7 per cent. of sugar, and the diastase that is present converts starch to maltose during cooking [15].

Sweet potato is similar to other roots and tubers in having a higher concentration of the non-carbohydrate nutrients in the peel than in the pulp, as indicated by the content of crude and pure protein, ether extract, crude fibre, and ash.

From its chemical composition and qualitative nutritive value, Ipomoea deserves more consideration in Nigeria as a source of readily

digestible and soluble carbohydrates, in the nutrition of livestock as well as of man.

Dioscorea spp. (Yams).—With the exception of the water or winged type, which probably spread from the eastern world, and the 'cush-cush' variety from America, yams are mainly native to Africa, in many parts of which several varieties are cultivated as human food. In Nigeria the yam is a useful source of good-quality starch for man, and it can also be so used for animals. It is generally too expensive at present to feed to livestock, but may occasionally be included in animal rations when grown on the farm. The peel is certainly of great value for this purpose. As far as is known, yams are free from cyanogenetic glucosides.

Dioscorea rotundata Poir. (White yam).—The colour of the flesh of the tubers of all known sub-varieties of *rotundata* is white, and it is undoubtedly the most popular type of yam grown in Nigeria. White yam, which is native to Africa, is characterized by its prickly stems and the opposite, heart-shaped leaves which fold downwards. It has better keeping qualities than the yellow yam and it is more adaptable for cultivation in the drier parts of the country than are the other varieties.

As the Tables show, white yam was appreciably lower than all the other varieties in crude and true protein, fairly low in crude fibre, and lower than the water yam in ash content, but high in soluble carbohydrates. Like the other yam varieties its calculated digestibility was high and, for a root crop, it is a good source of total nutrients. In the peel there was a concentration of the non-starchy nutrients, particularly protein and minerals, and since the peel forms about 10 per cent. of the total root, it constitutes a valuable source of food for ruminants and may even meet a large part of the production ration for these animals.

Dioscorea cayenensis Lam. (Yellow yam).—The flesh of the tubers of this variety is yellow, and it also has many sub-varieties according to the quality of its flesh. Yellow yams can be distinguished during growth from the white ones by their leaves, which are a much darker green, shorter, broader, and with more rounded leaf blades.

The specimens of the yellow yam analysed were richer than the white yam in protein, lower in ash and oil, and similar to it in starch and crude fibre, although there was less fibre in the edible portion of the yellow than of the white variety.

Dioscorea alata Linn. (Water yam or winged yam).—This is believed to have originated from the eastern tropics, but it is now widely cultivated in tropical Africa. The petiole of the leaves is usually winged. It is a very heavy yielder, penetrating deeply into the soil and thus requiring large 'mounds' or ridges. It is watery in texture and may be white, brown, or almost red: the sub-varieties are distinguished according to colour, shape, and taste.

This variety was much richer in protein and ash than were those already discussed. It was fairly low in crude fibre, and it seems a better source of digestible nutrients, with as narrow a nutritive ratio as either of the previous varieties. The peel was particularly rich in protein and ash, and its calculated digestibility was high.

Dioscorea dumetorum Pax. (Trifoliate yam).—This is not regarded as a true yam in southern Nigeria, since its taste is different from that of the other yam varieties, and it is considered to be of poorer quality. This idea was hardly supported by the chemical composition of trifoliate yam, which was found to be richer in crude protein and to have a narrower nutritive ratio than any of the other yams studied. It was, however, relatively poor in ash, which seemed to be highly concentrated in the peel, while its starch equivalent and total digestible nutrients were lower than those of the white yam. Its peel, like those of the other varieties, should provide a valuable feed for ruminants.

Dioscorea esculenta Burkill (Chinese yam).—The Chinese yam produces a number of small tubers which lie shallow in the soil; they are very sweet, with white flesh. This yam was next only to the trifoliate yam in its protein content and nutritive ratio, and similar to trifoliate yam in its ash content, starch equivalent, and total digestible nutrients. The peel, which is relatively thin, was richer than the edible portion in protein, oil, crude fibre, total ash, and silica-free ash.

Saccharum officinarum Linn. (Sugar-cane leaves).—The sugar-cane is a common crop found naturally in many low-lying damp places and near the streams in Nigeria. It is readily propagated by cutting and is by no means difficult to cultivate. Although the plant is grown in many parts of the world for its sugar content, the extraction of cane sugar is an industry yet to be established in Nigeria. It is well known here, however, that cattle, sheep, and goats relish sugar-cane leaves which thus constitute very useful fodder. A field of cane could be browsed by these animals or could be established for the production of fodder, hay, or silage.

The sample of leaves analysed was rich in minerals but poor in protein, had a low fibre content, and was fairly high in ether extract. Although sugar-cane leaves may need to be supplemented with a protein-rich concentrate when used as a production ration, they are nevertheless a valuable livestock food because of their carbohydrate and ash content, as well as their ease of propagation.

Talinum triangulare Willd. (Water leaf).—This is a fleshy herb which is widely consumed as a vegetable in Nigeria. It grows naturally from seed and may reach a height of up to 12 in. on its thin, fleshy stem when fully mature. It is known to be non-poisonous and highly nutritious. The herb is quick-maturing, soon flowers, and dies back within a few months; it rapidly propagates itself by means of its seeds.

As the Tables show, Talinum was very rich in ash, a good source of protein, and low in fibre, as well as in ether extract. It is highly palatable to stock and is very keenly sought after, particularly by domestic birds. Talinum could usefully be included in grazing pastures, mixed with grasses and legumes, where it would improve the palatability of the herbage. It could also be cut as hay, or added as a protein-and-ash supplement to other hay or silage.

Telfairia occidentalis Hook. (Fluted pumpkin: leaves).—The leaves of fluted pumpkin are well known in the eastern parts of Nigeria for their pleasant flavour, and they are often picked while the fruit is developing,

for inclusion as a vegetable in soup or stew. The plant is much sought after by sheep and goats, and as a result it is closely guarded in backyard gardens and on farms during its growth.

As Table 1 shows, the leaves are a rich source of protein, oil, and minerals. The ash content, although lower than that of talinum, was nevertheless considerable, whereas the content of crude fibre was low for leafy material. Telfairia leaves could prove a useful supplement in livestock rations, particularly as an additional source of ash and proteins.

Nutritive value of peelings.—The investigation described has shown that the non-carbohydrate nutrients of roots and tubers tend to be concentrated more in the peel than in the pulp. The peel of all the roots analysed consisted of an outer skin and an inner rind, the former being a somewhat richer source of protein, oil, and ash, while it contained a high proportion of crude fibre and silica (unpublished information). In yams the two layers make up about 10 per cent. of the whole, although the proportion varies with the size of the tuber. Thus Platt [16] showed that the peel might be as low as 5 per cent. in small and as high as 15 per cent. in large tubers. Peelings can therefore supply considerable amounts of animal feed.

The practice, common among many sheep and goat owners in Nigeria, of feeding these 'wastes' of yam, coco-yam, sweet potato, and cassava to their livestock is evidently a useful one, as the nutritively better balanced portions of the roots or tubers are thereby given to the animals, leaving the carbohydrate-rich portion for human consumption.

Summary

The chemical composition and the calculated nutritive values of the commonly grown roots and tubers, and certain leaves, used as fodder in Nigeria were examined. They were found to be valuable sources of carbohydrate, cassava being one of the richest in this nutrient. The least popular of the yam varieties, *Dioscorea dumetorum*, contained more protein, while water yam, *D. alata*, was somewhat richer in ash than any of the other roots.

The peels of these roots and tubers were relatively rich in protein, oil, and ash, as well as crude fibre. They should therefore provide a valuable addition to the nutrition of ruminants in those parts of Nigeria that grow roots and tubers in quantity.

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(*Received 13 October 1954*)

ESTIMATING THE DECREASE IN YIELD ON CEASING TO MANURE UNSHADED TEA

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NUMEROUS attempts have been made in the past to find mathematical expressions for the relationship between the amount of fertilizer applied and the resultant crop response [1]. In a perennial crop like tea, one is concerned with yet another aspect of the relation between manuring and yield. If the rate of manuring be changed in and from a given year, then the manner in which the yield changes in the years immediately following is of great practical interest and deserves investigation. The effect of ceasing to manure on the yield of tea is discussed briefly in this paper, an attempt being made to show that, under certain simplifying conditions, the changes in yield with time follow an exponential equation.

At the outset it should be pointed out that changes in the yield of tea can result from a variety of causes, and it is therefore necessary to specify certain conditions. The following discussion refers only to annually pruned mature tea under the conditions obtaining in north-east India. Young tea, where the yield increases steadily, and mature tea under longer pruning cycles are left out of the discussion. If the yields in different years are to be on a comparable basis then it is necessary that cultural practices such as the time of pruning, the tipping level, the method and style of plucking, &c., should remain unaltered from year to year: otherwise the changes in yield will be too complicated for calculation. Variations in climatic conditions, which are beyond human control, will also be reflected in the annual yields. In the analysis that follows, however, consideration is given only to the differences in yields resulting from two manurial treatments, and not to the intrinsic values for any one treatment.

It is desirable, at this stage, to describe the conditions obtaining in the tea areas of north-east India. Most of the soils of this region can be classified as 'New alluvium'. The predominant soil type is a loamy sand, with pH about 5·5, base-exchange capacity of the order of 5–10 m.e./100 gm. of soil, and comparatively low organic-matter status. For mature tea only a nitrogenous fertilizer is generally used, and the fertilizer found to be most efficient is sulphate of ammonia. The rate of application varies in individual cases, but the recommended application for unshaded mature tea is between 80 and 120 lb. of nitrogen per acre.

With no manuring at all, it is possible to maintain yields (Y_0) of the order of 400–480 lb. of made tea per acre in the Assam Valley. If the tea bushes be manured at a steady rate for a number of years, the yield attains a more or less steady level, the increase in yield being almost proportional to the quantity of fertilizer used up to fairly high crop limits [2, 3]. Now, suppose that an area of tea has been manured steadily for a number of years at, say, N lb. of nitrogen per acre, and that the yield has attained an

[Empire Journ. of Exper. Agric., Vol. 23, No. 90, 1955]

equilibrium value Y_N: if now manuring be discontinued from a certain year (year zero), then the yield will begin to decrease, and presumably in course of time it will drop to the level Y_0 which is attainable with no manuring at all. The manner in which the yield decreases may depend upon the residual effect on the soil of the fertilizer used and possibly the density of shade under which the tea is grown. It is known that the response of tea to fertilizer application varies markedly, depending on the shade density, and it is therefore possible that the effect of ceasing to manure may also differ with the density of shade.

In this preliminary discussion only the simple case of chemical nitrogenous fertilizer like sulphate of ammonia applied to unshaded tea will be considered. In this case it can be assumed that the fertilizer has no residual value, such as may occur with some forms of organic nitrogen, phosphate or potash, and there will be no complicating interaction with shade. Under these simple conditions it may be assumed, from first principles, that the rate of decrease in yield at any particular time will be proportional to the difference between the value of the yield at that time and Y_0. If y be the actual decrease in yield in the year t, after ceasing to manure, then the rate of decrease in yield at that time is given by

$$\frac{dy}{dt} = k(A-y) \qquad \text{(i)}$$

where A stands for the value $Y_N - Y_0$ and k is a constant. On integration, equation (i) becomes

$$y = A(1-e^{-kt}) \qquad \text{(ii)}$$

which is similar to the well-known equation proposed by Mitscherlich for the relation between yield and different amounts of a fertilizer.

A characteristic feature of the exponential equation is that the rate of

TABLE 1. *Effect of Ceasing to Manure: Comparison with Manured Tea*

Treatment		*Yield, maunds* tea per acre*		
		1931	*1932*	*1933*
A: Manured continuously		12·70	12·60	12·04
B: Manured up to 1930, thereafter unmanured		10·30	8·99	8·06
Least Sig. Diff., P = 0·05		0·65	0·71	0·86
Difference between treatments A and B	Actual	2·40	3·61	3·98
	Calculated	2·44	3·53	4·02

* One maund = 82 lb. approx.

decrease is highest at the beginning and diminishes gradually. The following two examples demonstrate that the decrease in yield of tea after ceasing to manure does in fact show this feature.

Experiment 1. Borbhetta area 33, jat of tea Suffry Lushai, unshaded, planting 5 × 5 ft. triangular, tea planted 1920. All plots received 200 lb. of sulphate of ammonia per acre annually up to 1930. Thereafter manuring was continued in the A plots but none was applied to the B plots. The results appear in Table 1.

An equation of the type $y = A\,(1-e^{-kt})$ can be fitted to the results, and the least-square solution is

$$y = 4{\cdot}41(1-e^{-0{\cdot}807t})$$

where y is the decrease in crop (mds./acre) on ceasing to manure, and t is the time in years after ceasing to manure. (Compare Fig. 1.)

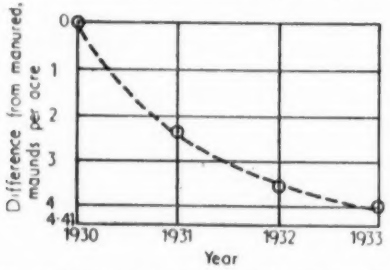

FIG. 1. Loss in crop, or decrease compared with manured tea, on ceasing to apply nitrogen (broken = calculated curve)

Experiment 2. Borbhetta area 19, jat of tea Matelli, unshaded, planting 4×4 ft. square, tea planted 1916. The A plots received 400 lb. of sulphate of ammonia per acre up to 1942, and manuring stopped from 1943. The B plots received no manure at all (check plots). The results are given in Table 2.

TABLE 2. *Effect of Ceasing to Manure: Comparison with Unmanured Tea*

Treatment		*Yield, maunds tea per acre*			
		1942	*1943*	*1944*	*1945*
A: Manured only up to 1942		17·33	8·95	4·92	5·34
B: Continuously unmanured		6·34	4·76	3·22	3·18
Least Sig. Diff., P = 0·05		1·24	0·98	0·62	0·92
Difference between treatments A and B	Actual	10·99	4·19	1·70	2·16
	Calculated	10·99	4·90	2·18	0·97

The difference between the yield of plots A and the check plots is given by $A-A(1-e^{-kt}) = Ae^{-kt}$. The least-square solution for the results is

$$10{\cdot}99e^{-0{\cdot}809t} \text{ maunds per acre}$$

and the equation for the decrease in crop after ceasing to manure is

$$y = 10{\cdot}99(1-e^{-0{\cdot}809t}) \text{ maunds/acre.}$$ (Compare Fig. 2.)

The value of k was almost identical in the two experiments, and it was independent of either the rate of manuring, the level of yield attained, or the kind of tea grown. It appears to be a characteristic of the soil conditions because (although evidence on the subject is not conclusive) it is a common observation that the rate of decrease on ceasing to manure is

faster, the sandier or poorer the soil. For a poor sandy soil like the one at Borbhetta the value of k may be taken as about 0·8, and in such soils the decrease in yield in successive years will be approximately as follows:

Year after ceasing to manure	*Decrease as percentage of* $A = Y_N - Y_O$
1	56
2	80
3	91
4	96
5	98

It will be noted that the yield drops very rapidly in the first and second years after manuring has ceased, and to maintain high yields manuring must therefore be continuous.

Caution is needed in applying these conclusions, because they are based on only two experiments covering relatively short periods of time. Confirmation from further experiments, in Assam and elsewhere, is

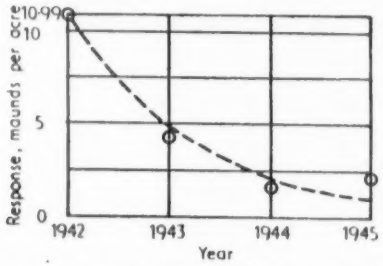

FIG. 2. Decrease in response, over unmanured tea, on ceasing to apply nitrogen (broken = calculated curve)

desirable. None the less, the results of the experiments were consistent with each other and with the theoretical approach. From the equations it is evident that the value of k determines the shape of the curve, and the higher its value the more rapid is the decrease. The scale, or the actual magnitude of the changes in yield, are on the other hand dependent on A. The value of A depends on the efficiency and the amount of the fertilizer used, as well as on the kind of tea grown and the local soil and climatic conditions. It has already been mentioned that the response to increasing amounts of nitrogen is approximately linear up to fairly high crop limits. The return per unit amount of nitrogen is not the same, however, for different kinds of tea or under widely differing soil and climatic conditions.

The procedure for calculation is the same whether manuring is discontinued altogether or merely reduced; all that is necessary for the purpose is to have estimates of the equilibrium yields for the two levels of manuring or of the value of A for the given conditions.

Where manuring is reduced it can be inferred that the successive

losses in yield, which result from halving the rate of manuring, will be only half of what might be expected from ceasing to manure altogether.

Summary.—With two experiments on unshaded tea in north-east India as a basis, the decrease in yield in the years immediately following cessation of manuring with nitrogen is examined. It is shown that, under certain simplifying conditions, the changes in yield with time can be calculated from an exponential equation, if equilibrium yields or the values of two constants are known. The yield drops very rapidly during the first and second years after ceasing to manure.

Acknowledgement.—The author wishes to thank the Indian Tea Association for permission to publish this work.

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(*Received 1 December 1954*)

A STUDY OF MEADOW HAYS FROM THE COCKLE PARK PLOTS. PART II. ASH CONSTITUENTS

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PREVIOUS workers, other than Lawes and Gilbert [1], have paid little attention to the ash of meadow hay and, even during recent times, it has been exceptional for any constituents other than calcium and phosphorus to be determined. This neglect was probably due, in earlier years at least, to an imperfect realization of the importance of the part played by some of the mineral elements in animal nutrition.

It is by no means certain that meadow hay which would generally be regarded as being of good quality will necessarily be of the highest mineral efficiency; such hay will contain a preponderance of the better grasses, and it has been shown by Fagan [2], Thomas *et al.* [3, 4], and others that these are inferior in respect of mineral content to many weeds and, indeed, to some of the poorer grasses. The authors have already shown in Part I of this paper [5] that the 'good' hays from the Palace Leas plots have a somewhat lower silica-free ash content than the 'poor' hays. This finding may not be without significance, although the reliability of silica-free ash as a criterion of overall mineral efficiency is uncertain.

The mineral efficiency of hay is obviously of importance, in that this food is often the only worth-while source of minerals in the winter rations of young store stock. On lowland farms, the hay fed nowadays will be very largely from temporary leys, although meadow hay, if available, is often preferred for calves. Hill and marginal farms, on the other hand, are dependent to a very large extent on their meadows, and hay alone may be used in the hand-feeding of in-lamb ewes during long periods of bad weather. While the need for supplementary minerals will depend, to some extent, on the character of the grazing, a mineral-rich hand feed will always constitute a very desirable insurance.

It is reasonable to anticipate that the effect of manuring on the mineral content of hay will be very marked; that this is so in the case of certain of the major elements is already known; nevertheless, the data are limited and information on the essential trace elements is almost non-existent. It was therefore considered worth while to examine the effect of different manurial treatment on those elements, both major and trace, for the determination of which reliable analytical methods were available.

Experimental.—A short historical review of the Palace Leas meadow-hay plots, with a description of soil conditions, manurial treatments applied, sampling procedure, and the preparation of analytical samples, has been given in Part I [5]. The weights of plant nutrients, other than nitrogen and those present in traces, applied annually to the plots, are shown in Table 1.

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The samples upon which proximate constituents were determined [5] were used for the work to be described here. The usual methods were employed for the determination of crude ash and silica, silica-free ash being obtained by difference. For calcium, phosphorus, magnesium, potassium, sodium, and chlorine, the methods recommended in a communication of the Imperial Bureau of Animal Nutrition [6] were adopted with certain minor modifications in technique. Iron was determined by the method of McFarlane as modified by Fullerton, Lyall, and Davidson [7], and manganese by that of Richards [8]. For copper and cobalt the

TABLE 1. *Average Amounts of Plant Nutrients Supplied each Year by Manurial Treatments (lb./acre)*

Plot No.	*Manures applied**	*Calcium* CaO	*Phosphorus* P_2O_5	*Magnesium* MgO	*Potassium* K_2O	*Sodium* Na_2O	*Chlorine* Cl
1	F.Y.M.,S/A,N/S, B/S, M/P	120	70	39	83	25·5	5·2
2	F.Y.M.	45	45	27	57·5	9·1	3·5
3	As No. 1, but in alternate yrs.	60	35	19·5	41·5	12·5	2·5
4	F.Y.M. in alternate yrs.	22·5	22·5	13·5	29	4·5	1·8
5	Double F.Y.M. every 4th year. Other fertilizers as No. 1 in other years	78·8	41·2	22·5	47·7	16·9	3·1
6	Unmanured	0	0	0	0	0	0
7	S/A	0	0	0	0	0	0
8	B/S	150	50	12	0	0	0
9	M/P	0	0	0	50	2·3	4·6
10	S/A, B/S	150	50	12	0	0	0
11	S/A, M/P	0	0	0	50	2·3	4·6
12	B/S, M/P	150	50	12	50	2·3	4·6
13	S/A, B/S, M/P	150	50	12	50	2·3	4·6

* For details and rates of application see Part I, Table 1 [5]. F.Y.M. = farmyard manure; S/A = sulphate of ammonia; N/S = nitrate of soda; B/S = basic slag; M/P = muriate of potash.

procedures of Sylvester and Lampitt as modified by Sandell [9] were used. The method of Stout, Levy, and Williams [10] was employed for the determination of zinc.

Results

The results of the ash analysis for the hay from the differently treated plots are given in Table 2.

Plots 7 and 11 produced hay of *calcium* content which was low by any standards, and markedly lower than that of any of the remaining plots. Plots which received farmyard manure, either alone or in conjunction with chemical fertilizers (Nos. 1, 2, 3, 4, and 5), were closely grouped in respect of calcium and contained less of this element than is normally found in hay of good quality. Basic slag, alone or with other chemical fertilizers, produced hay in which calcium was at a very satisfactory level. The two best sources of this element were Plots 6 and 9.

Those hays which were poorest in *phosphorus* came from the four plots which were least adequately fertilized (Nos. 6, 7, 9, and 11); not one of these plots has, in fact, received phosphorus in any form. All remaining

plots of the series have done better than the foregoing but, if Plot 1 be excepted, they showed little difference in respect of phosphorus content.

Magnesium contents of all hays appeared to be rather low. While there was no obvious relationship between treatment and the percentage of this element present, there seemed to be some tendency for the application of manurial dressings which were incomplete in one respect or another to reduce the magnesium level.

The proportion of *potassium* present in the hay bore a fairly close relationship to the potash which was applied in manures and fertilizers. Plots 6, 8, and 10, which received no potash in any form, produced the

TABLE 2. *Ash Constituents of Hays*

(*On dry-matter basis*)

Plot No.	*Calcium* CaO	*Phosphorus* P_2O_5	*Magnesium* MgO	*Potassium* K_2O	*Sodium* Na_2O	*Chlorine* Cl	*Iron* Fe *p.p.m.*	*Manganese* Mn *p.p.m.*	*Copper* Cu *p.p.m.*	*Cobalt* Co *p.p.m.*	*Zinc* Zn *p.p.m.*
	%	%	%	%	%	%					
1	0·65	0·64	0·12	1·93	0·14	0·73	92	86	9·6	0·17	32
2	0·62	0·55	0·12	1·78	0·20	0·48	118	101	8·8	0·17	29
3	0·57	0·56	0·17	1·62	0·25	0·55	125	168	9·2	0·16	36
4	0·53	0·56	0·24	1·16	0·15	0·58	80	129	9·4	0·17	25
5	0·52	0·52	0·21	1·33	0·15	0·66	69	169	5·4	0·16	31
6	0·97	0·33	0·23	0·98	0·14	0·54	83	362	6·0	0·19	37
7	0·30	0·30	0·12	1·23	0·10	0·48	240	314	6·4	0·14	37
8	0·87	0·58	0·21	0·74	0·16	0·43	186	213	9·2	0·14	45
9	0·92	0·31	0·20	1·30	0·09	0·56	109	396	7·6	0·20	43
10	0·91	0·57	0·10	0·62	0·29	0·44	94	282	5·8	0·15	40
11	0·34	0·34	0·12	1·01	0·04	0·41	92	344	6·6	0·16	31
12	0·78	0·56	0·12	1·10	0·20	0·61	60	135	7·4	0·18	31
13	0·72	0·55	0·16	1·12	0·18	0·68	84	368	8·2	0·18	35

hays of lowest potassium content, but the position of Plot 7 (sulphate of ammonia only) was exceptional. That dung was a particularly good source of potash was indicated by the fact that the three hays of highest potassium content all derived from plots which received dung, with or without a potash salt.

The lowest *sodium* contents were found on Plots 7, 9, and 11, the soils of which in no case have a pH of more than 5·0 [5]. It will be noted that, with one exception (Plot 1), plots which received basic slag, with or without other manures, produced hay of relatively high sodium content.

The highest *chlorine* contents were found in hay from plots which received a complete dressing of chemical fertilizers every year (Nos. 1 and 13). While it is not easy to group the remaining plots, there was a general tendency for the hay to have a low chlorine content where no chloride had been applied in the manure; Plots 2 and 11 behaved exceptionally.

Although the highest *iron* content was found in hay from Plot 7, the soil of which has a pH of 4·5, there was no obvious relationship throughout the series between soil reaction and iron uptake; nor was it possible to establish a correlation with manurial treatment.

In general, as was to be expected, hays from plots of high pH contained relatively small proportions of *manganese*, while those from plots with a markedly acid soil reaction were rich in this element. Where farmyard manure and/or basic slag had been applied, manganese tended to be low; where nitrogenous and/or potassic fertilizers had been used it was high.

Of the five plots which yielded hays containing the largest proportions of *copper*, four received farmyard manure with or without supplementary chemical fertilizers. Plot 5 behaved exceptionally, having actually produced hay of the lowest copper content. Copper did not appear to be related to pH or to the supply of any particular class of chemical fertilizer.

Cobalt contents were generally relatively high, there being no single figure below 0·14 p.p.m. Three of the plots, which had received no potash in any form (Nos. 7, 8, and 10), produced hay containing the least cobalt, but Plot 6 did not conform, having grown hay with the second-highest cobalt content.

The range of values for *zinc* was not very wide, but plots which received chemical fertilizers only produced hay containing more of this element than plots which received farmyard manure, whether or not supplemented with chemical fertilizers.

Discussion

Hays from Plots 6 and 9 proved to be the best sources of calcium. Neither of these plots can be said to have received the sort of treatment calculated to produce a mineral-rich herbage, and the soil pH of both is low (5·1 and 5·0 respectively). A study of the botanical composition of the swards, however, showed that both contain relatively large amounts of weeds with, in addition, moderate amounts of clover. Among the former, ribgrass (*Plantago lanceolata*) predominated and there was a lesser amount of yellow rattle (*Rhinanthus crista-galli*); it has been shown by Thomas and his co-workers [3, 4] that these two species are exceptionally rich sources of calcium.

It has long been known that the application of basic slag to grassland produces a calcium-rich herbage [3, 11]. It is thus not surprising to find that all plots which received basic slag, with or without additional chemical fertilizers, have grown hay containing not less than 0·72 per cent. CaO in its dry matter. Inspection of Table 1 indicates that the superior calcium content of the hays from plots receiving basic slag (Nos. 8, 10, 12, and 13) over that of hays from the farmyard manure plots (Nos. 1–5) was due to the difference in the amount of lime supplied by the two treatments. The hays of lowest calcium content were from Plots 7 and 11, neither of which has received lime in any form since the beginning of the experiment, and both of which show exceptionally low soil pH values as a result of the application of sulphate of ammonia.

While Plots 6 and 9 are in similar case, having never received any lime-containing fertilizer, neither have they had sulphate of ammonia; in consequence, the pH of both is at a substantially higher level than in Plots 7 and 11. It is probable that, in general, the chief factor in determining the calcium content of hay is the amount of soil calcium available to the plant; at the same time, the occurrence of high proportions of broad-leaved species can, on occasion, be an equally important factor.

There was a significant positive correlation between pH and phosphorus content over the whole series of plots, and the limiting effect of pH on the availability of soil phosphorus has been pointed out by Russell [12] and others. It is obvious, however, that there was also some relationship between the phosphorus supplied as manures and fertilizers, and the phosphorus content of the herbage. As Table 1 shows, Plots 6, 7, 9, and 11 received no phosphorus in any form during the whole period of the experiment; these plots produced the hays of the poorest phosphorus content. Plot 1, which had the highest hay phosphorus of the series, received the largest application of this element. The effect of phosphatic fertilizers on the phosphorus content of herbage is well known, having been demonstrated by Beeson [13] and others.

There was no evidence that either manurial treatment or soil reaction had any effect on magnesium uptake. There is one factor, however, which may have affected the magnesium content of the hays, viz. the weed and clover content of the swards, for it is well known that the non-graminaceous species of grassland are of higher magnesium content than the grasses. Here some sort of pattern does emerge, for the four plots with the largest proportions of grasses (Nos. 1, 2, 7, and 11) were all of low magnesium content. Where the proportions of weeds and clovers were relatively large, as on Plots 6, 8, and 9, there was a tendency for hay of high magnesium content to be produced. In general, the hay from these Palace Leas plots was poor in magnesium, all figures for this element comparing unfavourably with values quoted by Morrison [14] and others.

Russell [12] has said that the potassium content of herbage may be low where only phosphatic and nitrogenous fertilizers are used, and this is well borne out by the results which were obtained here. Plots 6, 8, and 10, which produced hay of the poorest potassium content, received no potassic or potash-containing fertilizers during the whole course of the experiment. Hay from the remaining plots, with the single exception of that from No. 7, has obviously had its potassium content determined by the weight of potassium applied either as potassic fertilizer or in the form of farmyard manure. Plot 1, which has had at least 50 per cent. more potash than any other plot, has produced hay with the greatest potassium content. In view of the foregoing, it was no surprise to find that there was a significant positive correlation between the available potash contents of the soils [5] and the amounts of potassium in the hay. With only one or two exceptions, the hays from these Palace Leas plots were rather poor in potassium, if comparison be made with the corresponding figures quoted by Woodman (1·60 per cent. K_2O).

Although the sodium content of the hays might appear to be related

to the pH of the soil, a significant correlation coefficient was not obtained. Two manurial effects were evident, viz. (*a*) chemical fertilizers other than slag, with or without the addition of farmyard manure, resulted in low sodium uptake; and (*b*) basic slag, whether alone or in conjunction with other chemical fertilizers and/or farmyard manure gave hays of fairly high sodium content. Chlorine applied as potassium chloride may be the only factor capable of influencing the uptake of this element. Of the seven plots which receive potassium chloride, six produced hays having a chlorine content of 0·55 per cent. or more, whereas only one other plot (Plot 4) came within this range. Plot 11 provided an exception, having grown the hay of lowest chlorine content; whether this was in any way due to the very low pH of the soil (4·3) the authors are not prepared to say.

All determinations of trace elements are liable to serious error by reason of soil contamination. It should therefore be recorded that Raven [15] has shown that there was no appreciable degree of such contamination in these samples.

With one or two exceptions, the iron contents of the hays were not remarkably high; Plot 7 produced hay containing a markedly greater amount of this element than any other. This result is confirmatory of the findings of Thomas and Thompson [3], who showed that the predominant herbage species on this plot were all high in iron. The authors are unable to identify the factor or factors responsible for iron uptake, there being no apparent relationship with manurial treatment, pH of soil, or botanical make-up of sward on these plots.

Manganese presented a much clearer picture, for there was a significant negative correlation between the pH values of the soils and the manganese contents of the hays; this result might have been anticipated, as the relationship has often been demonstrated. The fact that plots which have received farmyard manure or basic slag, whether with or without other fertilizers, produced hay of relatively low manganese content, can probably be attributed to the positive effect which the treatments have had on the pH. Most of the manganese figures appear to be higher than the average for meadow hay, although remarkably little information is available on the point.

Hudig [16] and others have shown that dung is an excellent source of copper, and it is clear that the application of farmyard manure influenced the copper content of these hays, four of the five plots which received farmyard manure having produced hay of relatively high copper content. It was probably incidental that high copper uptake occurred at soil pH levels of 5·6 or more, these values being consequent on the buffering effect of the dressings of farmyard manure. Maynard [17] has postulated a figure of 7·5 p.p.m. as an adequate copper content for herbage. If this figure be accepted, then almost half of the plots on Palace Leas produced hay which would be an unsatisfactory source of the element.

The chief factor in determining cobalt content appeared to be the botanical constitution of the herbage. The four swards of highest cobalt content (those on Plots 6, 9, 12, and 13) all contained comparatively large amounts of herbs and clovers, and it is known that both these

groups contain rather more cobalt than the grasses. The cobalt content of all samples must be regarded as good when judged by the accepted standards. There is some evidence that both manurial treatment and botanical make-up influenced zinc content. Those plots which received dung and those which had chemical fertilizers only tended to produce hays of low and of high zinc content respectively. High zinc content hays, with one exception (Plot 7), had a fairly high content of weed and clover.

Any attempted summation of the mineral efficiency of the hays from the better-treated plots on the one hand, and from the poorly-treated plots on the other, will show that the former were, on the whole, rather better, being superior to a greater or lesser degree in respect of five elements, viz. phosphorus, potassium, sodium, chlorine, and copper. They were clearly inferior in manganese.

It was shown in Part I of this paper [5] that the quality of the hay produced on the Palace Leas plots, as assessed on the basis of digestible crude protein and starch equivalent, was inversely related to the goodness of manurial treatment. Two factors were held to be concerned in this effect, viz. species differences and maturity differences. On the assumption that the latter factor would not operate under practical conditions, it was suggested that unsatisfactory manurial treatment was probably without adverse effect on the quality of the hay. If differences in mineral efficiency be taken into account, however, the effect of good manurial treatment is to produce hay which, under certain circumstances at least, would be of higher nutritive value.

Summary

Ash constituents, including both major and trace elements, of hays from thirteen plots on the Palace Leas meadow hay field at Cockle Park have been determined.

Those plots which had satisfactory manurial treatment produced hays which were superior in respect of most of the important ash constituents. Hays from poorly treated plots contained more manganese.

On most plots the amount of any particular ash constituent present in the hay was determined by the amount supplied in manures and fertilizers. In a minority of cases, the pH of the soil or the botanical make-up of the sward could be related to the uptake of the element.

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(Received 27 September 1954; as revised, 27 January 1955)

MARROWSTEM KALE SILAGE

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METHODS of ensiling marrowstem kale have been reviewed by Watson [1], and the ease with which this crop can be successfully ensiled is apparent from the experiments quoted. There is, however, a high loss of nutrients in the ensiling process: Ferguson has shown that as much as 32–35 per cent. of the total dry matter ensiled may be lost [2]. Ferguson also showed that a high dry-matter addition, in the form of straw, had little effect on the loss incurred in the mass apart from slightly reducing the amount of water lost; and Watson emphasized that the straw lowered the feeding quality of the silage. Edin [3], using acid additions, obtained losses of the same order as Ferguson, but Hellberg [4], employing small glass silos, found that losses decreased from 19 per cent. to 10 per cent. of the dry matter when the size of chopped kale ensiled was lowered from 10 cm. to 1 cm. in length. More recently, Barnett [5], using silos of about 2 cwt. capacity, obtained losses in the range of 13–26 per cent. of the dry matter. If losses as low as those quoted by Hellberg and Barnett could be obtained in practice then kale silage would be a much more attractive proposition to the farmer, and further work on the problem seemed called for.

Experiments on the ensiling of kale, carried out at this Institute in 1945 and 1946, gave losses very similar to those reported by Ferguson (Castle and Foot, unpublished results). In this series of trials the losses fell within the range of 38–54 per cent. of the dry matter and 36–49 per cent. of the crude protein ensiled; 6–10 per cent. of the dry matter and 5–8 per cent. of the crude protein were shown to have been lost by seepage from the silo. An addition of dried beet pulp was made to some of the kale before ensiling, but it did not materially decrease the losses in the silo.

Experimental.—In the autumn of 1951 two tower silos holding approximately 15 tons and two small silos with a capacity of 10 cwt. were filled with chopped marrowstem kale. Two different treatments were compared in the large silos, Silo 1 having kale only whilst hay was added to the kale in Silo 2 at the rate of 12 per cent. by weight. The two small silos (3 and 4) were filled with chopped kale and no addition was made. As the high loss of nutrients in kale silage has been attributed to seepage from the silo, the hay was added with the dual object of absorbing excess moisture in the mass while overcoming the disadvantage of adding straw, which substantially lowers the feeding quality of the silage. Some difficulty was encountered from the separation of hay and kale after passing through the cutter-blower: the hay being lighter tended to be blown to the side of the silo, leaving the heavier kale in the middle. Because of this, the hay and kale had to be mixed in the silo by hand. The kale was ensiled in all four silos between 10 and 12 December, and as the weather

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was fairly cold the major part of the kale was frozen during the filling period.

Thermocouples were inserted at four points from top to bottom in the large silos, temperatures being noted throughout the whole ensiling period. The effluent from all silos was collected and samples were taken at frequent intervals for dry-matter and crude-protein determination.

Each load of kale filled into the silos and of silage taken out was weighed and sampled and the dry-matter content determined for each sample. The crude-protein content of the silage was determined from the fresh material, and the bulked dry materials were analysed by the conventional methods for the other fractions.

Results.—The composition of the kale and the silages is detailed in

TABLE 1. *Composition of Kale and Kale Silage*
(per cent. on dry-matter basis)

	Silo 1		*Silo 2*		*Silo 3*		*Silo 4*	
	Kale	*Silage*	*Kale*	*Silage*	*Kale*	*Silage*	*Kale*	*Silage*
Dry matter	15·39	16·47	14·75	18·13	14·56	17·27	14·56	17·45
Dry matter of hay	..	..	79·31	..	..	..	..	..
Crude protein	13·1	12·0	11·3	14·0	14·8	14·4	14·8	14·4
Ether extract	1·6	2·0	1·5	2·1	2·0	2·9	1·8	3·0
Nitrogen-free extract	57·9	52·0	52·7	43·5	54·8	50·1	55·6	47·7
Crude fibre	16·2	22·8	23·0	27·2	14·6	19·1	13·9	19·4
Ash	11·2	11·2	11·5	13·2	13·8	13·5	13·9	15·5
'True' protein	7·8	7·3	8·4	9·0	10·1	8·6	10·2	8·9
Dry matter of effluent	7·5		6·7		7·1		6·8	
Crude protein of effluent	17·0		21·0		19·8		18·4	

Table 1. The dry-matter content of the kale before ensiling was 14·6–15·4 per cent. and of the resulting silage 16·5–17·3 per cent. The increase in dry-matter content was probably due to drainage from the silo, and the true difference was probably higher as the dry matters were not corrected for loss of volatiles in the drying process. With the addition of hay (dry-matter content 79·3 per cent.) the dry-matter content of the silage was 18·1 per cent. The crude-protein content of the kale going into the small silos was higher than that ensiled in the larger silos (14·8 per cent. as compared with 11–13 per cent.), and with the exception of the hay-kale mixture the silage had a lower protein content than the ingoing kale.

There was very little difference between the dry-matter contents of the effluents from the large and the small silos, which fell within the range of 6·7–7·5 per cent. The crude protein in the effluent amounted to 17–21 per cent. of the dry matter.

Losses occurring in the silages and the effluents are summarized in Table 2. The losses of dry matter in the two large silos were high, that from hay-kale silage being higher than from kale only (37·8 and 32·5 per cent. respectively). In the small silos the total losses were much lower (23·9 and 25·1 per cent.), in spite of a greater loss of dry matter in the seepage. The crude-protein loss in the large silo, where no addition was made, was 38·2 per cent. and in the smaller silos 26·1 and 27·2 per cent.

All the other fractions of the analysis, with the exception of the 'true' protein, showed lower losses in the small silos than in the large one.

In the two large silos the loss of dry matter in the effluent was small

TABLE 2. *Losses in Kale Silage* (*per cent.*)
(+ = gain)

	Silo 1	*Silo 2*	*Silo 3*	*Silo 4*
Dry matter	32·5	37·8	23·9	25·1
Crude protein	38·2	..	26·1	27·2
Ether extract	15·7	..	+10·3	+23·7
Nitrogen-free extract	39·4	..	30·5	35·8
Crude fibre	5·0	..	0·4	+ 4·5
Ash	32·5	..	25·5	16·6
'True' protein	36·8	..	35·2	34·7
Dry matter in effluent	4·6	6·9	14·6	14·9
Crude protein in effluent	6·0	..	19·5	18·6

considering the low dry-matter content of the crop ensiled. The hay addition increased seepage losses, which may have been due to the hay opening up the mass and allowing freer drainage than there would be in a tightly packed mass of chopped kale. The loss of dry matter in the

TABLE 3. *Temperatures in Silos* (°*F.*)

Weeks after ensiling	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SILO 1, KALE:											
1st thermocouple (bottom)	44	41	41	38	35	37	38	42	45	45	46
2nd ,,	30	32	34	31	29	31	32	39	43	45	45
3rd ,,	32	33	40	36	35	36	35	39	44	45	47
4th ,, (top)	33	74	48	41	43	37	37	39	44	42	43
Mean temperature	35	45	41	37	36	35	36	40	44	44	45
SILO 2, HAY-KALE:											
1st thermocouple (bottom)	32	31	33	31	29	31	31	50	54	54	55
2nd ,,	31	32	33	31	29	31	32	50	53	53	53
3rd ,,	32	35	38	36	35	38	39	48	51	51	52
4th ,, (top)	33	56	54	45	45	45	44	47	48	48	48
Mean temperature	32	39	40	36	35	36	37	49	52	52	52

seepage from the small silos was more than double that from the larger ones, and the loss of crude protein showed an even greater difference.

The pH values for all four silages were low (4·1–4·2), and showed little variation between silos. From appearance the silages had undergone a normal fermentation, and the low pH values show that the silages had a high lactic-acid content, in spite of the low temperatures recorded during the ensiling period.

The temperatures recorded in the large silos are shown in Table 3. At the time of ensiling, the temperature of the kale was very low (32° and 35° F.). Little or no rise in temperature took place until 6 weeks after filling, except in the top layers of the silage where there was a slight increase. The length of time that the temperature persisted at this low

level was surprising, but may have been partly due to the thermocouples being placed in the middle of the mass where insulation would be best. There were no substantial differences in temperature between the silages, apart from the hay-kale silage heating up rather more quickly than the other after the sixth week.

Discussion.—The high loss incurred in ensiling marrowstem kale was again shown in this trial. Such losses have been attributed to the large amount of seepage taking place from the silo, but here the losses of dry matter in the effluent from the large silos were fairly low considering the dry-matter content of the ingoing kale, and the high total loss does not appear to have been due to the seepage.

Hay was added to the kale at the time of ensiling with a view to soaking up the excess moisture in the kale silage and thus lowering the amount of seepage. Instead of this the hay appeared to open up the mass, thus allowing freer drainage and raising effluent losses. Although the hay-kale silage was of good quality, it was in no way superior to silage made from kale without any addition, so that the addition of hay neither improved the quality nor reduced the amount of effluent in kale silage.

There was a striking difference between the losses in the small and the large silos, the total losses in the small silos being much lower than those in the larger silos (25 and 35 per cent. of the dry matter respectively). Effluent losses were much higher in the small silos, giving an even greater difference between the small and large silos for fermentation and respiration losses (29 per cent. of the dry matter for the large, and 10 per cent. for the small silos). As some of the earlier work was done on a small scale, this difference might well account for the wide divergence of losses found in experiments on ensiling kale.

In spite of the low temperatures prevailing in the kale silage, a normal fermentation took place. The dry-matter content of the kale was low, and this in conjunction with the low temperatures should produce, on the generally accepted principles of silage-making, a poor-quality silage. This, however, did not occur, and it is probable that the high sugar content of the kale made a lactic fermentation possible despite the other adverse factors.

Summary.—Marrowstem kale ensiled on a large scale, without addition, was subject to high losses. The total losses were less when small amounts of kale were ensiled, but effluent losses were increased. Chopped hay added to kale, at the time of ensiling, had no beneficial effect on the quality of the silage nor on the amount of seepage.

Acknowledgement.—The authors wish to thank Mr. A. W. Wagstaff for assistance with the analyses.

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(*Received 13 December 1954*)

RECENT INTRODUCTIONS TO WEST AFRICA OF *THEOBROMA CACAO* AND RELATED SPECIES

I. A REVIEW OF THE FIRST TEN YEARS

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FROM the 1954 main cocoa crop in the Gold Coast it is estimated that 65,000 pods of the recently introduced types of Upper Amazon cacao will be available for distribution as planting material to farmers [1]. This should produce over two million seedlings, and an ever-increasing number will be available with each succeeding crop. Within the next decade the effect of this new type of cocoa on the West African market will be considerable. It is the object of the present paper to review the characters and performance of these introductions during their first 10 years in West Africa.

Source of material.—Material from Pound's expedition of 1937–8 [2] to Ecuador, the Amazon Valley, and Columbia was brought together in Trinidad after a period of quarantine in Barbados. From this collection both open- and hand-pollinated pods were dispatched by air to the Gold Coast during 1944 [3]. A smaller number of pods from wild-type 'Lower Amazons' collected by Myers [4], together with some local Trinitario and Criollo types, completed the *Theobroma cacao* shipment from Trinidad. Each pod was designated by a serial number with the prefix 'T'; numbers below T60 were open-pollinated whilst those above T60 were hand-pollinated. After a period in quarantine at Accra the resulting seedlings were planted at Tafo in 1945. They were planted at a 14 × 14 ft. spacing. Seven other Theobroma species and two Herrania species were also included in the introduction.

Representatives of each of the four large population groups distinguished by Pound in South America are now growing at Tafo. From the breeding point of view the most important of the four South American groups is the population of the headwaters of the Amazon. To the west of this group occurs the Nacional population of Ecuador and the Peruvian Cordilleras. To the north occurs the Venezuelan and Colombian Criollo population, while to the east occurs the Amelonado population of the Guianas. Pound considered that there had been no serious overlapping of these groups except in the valley of the Orinoco, where the Trinitario complex was formed by the hybridization of the Criollo and Amelonado groups.

An alternative theory is that the Trinitario complex originated in the island of Trinidad, by a natural mixing of Criollo surviving the blast disease of 1727 and subsequent cacao introductions from eastern Venezuela.

[Empire Journ. of Exper. Agric., Vol. 23, No. 90, 1955]

3988.90

A: Theobroma cacao

Upper Amazon population.—All types within the Upper Amazon population have completely unpigmented (i.e. ripening yellow) pods and heavily pigmented cotyledons. The stamens are usually pigmented and the spatulate end of the petal frequently shows a red 'break'. Within the group there is a diversity of morphological characters as well as variation in yield, in bean size and quality, and, to a lesser extent, in susceptibility to pests and diseases. All members of the headwater population represented at Tafo are self-sterile and possess a unique incompatibility system [5]. The types are named after the geographical area or river system in which they were located by Pound.

The Scavina (T12) trees have a very tall habit of growth with short, often weeping, branches whose foliage is a dark green. The petioles are thin and of medium length. The pod ripens yellow, and is flat-sided and ten-furrowed, with the alternate broad furrows deeper than the narrow ones. The surface is moderately warty and rarely smooth. There is a slight but high bottle-neck, and the pod tapers either to a blunt indented point or one which is constricted and lemon-like. The flowers, apart from the staminodes, are devoid of red pigment except in a few trees which have a slight 'break' in the petal.

There are a number of Nanay selections, both open and controlled crosses, in the collection at Tafo. The open-pollinated Nanay types (T11, 13, 14, 15) appear to have been crossed with a Trinitario. Many stands bear Trinitario-type pods and flowers with petals having large elongated spatulate ends. They resemble the flowers of I.C.S. 85, the probable male parent. The Nanay × Nanay trees are moderately vigorous. A proportion of the stands have not in the first 10 years developed a leading chupon (upright branch) and have remained at the level of the first jorquette (point of forking). The branches tend to be spreading. The type T61 (Na 33 × Na 32) has pigmented stamens with no petal break, whereas with T62 (Na 33 × Na 34) both stamens and petals are pigmented. In types T81 and T92 (Na 32 × Na 31) the flower pigments are less pronounced and there is segregation for both stamen and petal colour.

Pound described the Nanay pod as being unpigmented, long, oval in shape, only slightly warty, and half blanco, possessing neither conspicuous point nor bottle-neck. The Nanay progeny at Tafo bear pods which are small with flattened sides, having shallow furrows with either a slight or no neck. The leaves have short petioles with little distinction between pulvini.

The Parinari group is represented by open-pollinated types T30 and T53, and a Parinari × Parinari, T86 (Pa 35 × Pa 7). The Parinari pod was described by Pound as being long, generally warty, with a pronounced bottle-neck and a conspicuous point. This 'lagarta' or Parinari type appeared to be general on the Rio Marañon. The open-pollinated representatives of this group at Tafo tend to be tall with short branches, and the pods agree with Pound's description. The cross T86 (Pa 35 × Pa 7), is moderately vigorous and tends to be spreading. There is here a

variation in the pods, some having smooth and others rough walls. The plumper pods have no neck whilst the more oval types have a neck. Contrary to the description given by Posnette [6] a high proportion of stands bear flowers with pigmented stamens and a red break in the petal. The petioles tend to be long, with a distinction between pulvini.

The Iquitos Island types T16 and T17 are both open-pollinated, and the typical pod is similar to Amelonado but larger and more rounded. All flowers have pigmented stamens and a red break in the spatulate end of the petal. Studies of the incompatibility system have shown that T16 has a proportion of the progeny which are self-compatible. The male parent was probably a Trinitario cacao.

The trees representing the Morona type (T55, T56) result from beans of an open pollination. Pound [2] reported that the 'lagarta' type of pod did not occur in the upper reaches of the Rio Marañon, and only the short oval type was found in the region of the Rio Morona. The male parents of the Morona types at Tafo were certainly Trinitarios, and consequently few of the trees bear the typical Morona dark-green pod, which has a waxy bloom and a mealy appearance between the furrows as described by Pound.

The most vigorous Upper Amazon types at Tafo are the progeny resulting from crosses between the Upper Amazon groups. The Nanay-crossed Parinari types contain stands with both warty and smooth surfaces. The smooth-surface pods are half-blanco, with a high, wide, and slight bottle-neck. All pods tend to be oval. There is a segregation for pigmented stamens. Crosses between the Parinari or Nanay and the Iquitos types tend to bear pods with the shape of the Iquitos parent.

Ecuador population.—The collection at Tafo contains a number of types selected by Pound from estates in Ecuador. Few of this group have done well, and some of the controlled-pollinated types T77 (a selfed M236) and T78 (a selfed M234) are the weakest in the whole collection. The Ecuador types are not likely to yield any characters of economic importance to West Africa. Only one representative of the group shows considerable vigour and that is T3, which is the progeny of an open-pollinated pod of I.C.T.A. No. E1. This type was collected from the Pacific side of the Andes and has many characters similar to Nacional cacao. The trees are vigorous with only a slight segregation for pod shape. The pods are long, oval, and very warty, slightly bottle-necked, with a somewhat waxy surface. The beans are plump and paler in colour than the Upper Amazon types. Three trees among thirty-nine of the type are quite distinct, having fat red pods and large flowers. This is an unusual segregation both in number and form. It may well be that the T3 pod resulted from a double pollination. The Ecuador types have pigmented stamens similar to certain of the Upper Amazons but the pigmentation in the stamen and petal is more intense. It is hoped that pigment analysis of both stamen and petal, together with the incompatibility studies, will throw some light on relationships between the various populations.

Criollo population.—The Criollo population representatives have not done well, as most have been very susceptible to capsid attack. The

Nicaraguan Criollo (T27, T48) is vegetatively less vigorous than the Venezuelan Criollo (T28, T49). All four bear pods with the characters of their respective American populations; i.e. the Venezuelan Criollo has a less well-defined point and a predominance of red pods compared with the Nicaraguan Criollo. Although these types have large, plump beans they are not likely to be of any importance to the cocoa industry or cacao breeding, as the Criollo quality is not required by the manufacturers in their bulk cocoa from West Africa.

Trinitario complex.—There are seventeen different 'T' numbers representing the Trinitario complex in the collection at Tafo. Nine of them are progeny from open-pollinated pods of Imperial College (I.C.) selections and, as would be expected, there is considerable tree to tree variation. A Trinitario from Costa Rica, T9 (possibly derived from a United Fruit Company clone), is outstanding at Tafo, having large pods with good-sized beans and a high early yield. A variable number of white beans occurs on stands in the selection.

Should clones be used as planting material in West Africa, then further testing of Trinitario selections would be necessary. First indications from the clonal trials at Tafo are that I.C. clones are not successful in West Africa, but the introduction of these clones in 1944 was a limited one. In 1954 a second introduction of I.C. clones was made, and these clones could be used if tests prove them to be superior in yield to existing selections.

Lower Amazon.—The pod of the Maranhão type T6 came from St. Augustine, although the grandparent tree grew in Bahia, Brazil. Similarly the Surinam pod T7 came from a tree at St. Augustine, although the original selection of the grandparent was made by J. G. Meyers in Surinam in 1929.

Although T6 is termed 'Maranhão', the pods fit exactly the description given by van Hall [7] for the 'Common cacao' of Bahia and do not agree with the description of the 'Maranhão cacao'. The T6 progeny are vegetatively vigorous, and tend to be lower and more spreading than many other types. The pods are uniform, being plump-oval, shallow-furrowed, and smooth, with a slight or no bottle-neck. It is interesting that a type coming originally from Bahia should have stamens which are well pigmented and petals having a very pronounced red 'break', because of the similarities of these characters with those found in the Upper Amazon groups. The ligule tends to be longer than that of the normal Forestero flower; the beans have a purple cotyledon.

The Surinam progeny (T7) are vegetatively vigorous. The pods are long-oval with shallow furrows, the bottle-neck is slight to medium, and the point may be either pronounced or absent. Most are pink on green, while a few are yellow. The beans are large with a light-purple-coloured cotyledon. The flowers have unpigmented stamens and petals.

Development Work

Interim distribution.—The primary object of introducing new cocoa types to West Africa was to have available for the breeding programme a greater genetic variability.

In the interim period of producing new varieties, certain of the introductions have been distributed to the Departments of Agriculture in the Gold Coast and Nigeria, and small shipments have been made to research stations in other territories. It was soon recognized that many of the introductions were considerably more vigorous than the local Amelonado cacao. The Commission of Inquiry into the Swollen Shoot Disease [8] reported in 1948 that the Amazonian types must be of importance in the rehabilitation programme. It was recommended that all such material available should be increased as rapidly as possible, but should be under the closest control by the West African Cacao Research Institute (W.A.C.R.I.).

The first distribution of pods to the Department of Agriculture, Gold Coast, was made on 1 May 1949, and shortly afterwards a consignment was sent to Nigeria. By 1954 over 16,000 F2 pods had been received by the Department of Agriculture, Gold Coast, and 600 acres of Upper Amazon cacao had been planted for the production of seed. The policy in the Gold Coast has been to plant all F2 pods, that is pods from the 'Introductions Area', W.A.C.R.I., as they become available, firstly on Department of Agriculture cocoa stations and later on farmer's holdings. On these latter plots, known as 'gentleman's agreement plots', the Department retains the right to eliminate any selections which prove to be undesirable. A proportion of the crop is given to the farmer. From the seed plots F3 pods, or F3 bare-root seedlings, are being distributed to farmers. The first F3 pods to be produced by the Department of Agriculture were delivered to W.A.C.R.I. and fermented. In this way the beans from over 29,000 F3 pods were fermented and sent to the manufacturers in the U.K. and U.S.A. for making up into chocolate samples.

As a result of the quality tests the number of 'T' types regarded as suitable for distribution has been reduced to the ten listed below [9]. F3 pods from these ten approved types are being distributed to Departmental nurseries for planting with a view to later issue to farmers as bare-root seedlings. The scale of distribution is rapidly building up, and by 1955 several million seedlings should be available in the Gold Coast.

The ten types approved for distribution to the farmer are:

T60 (Pa 7 × Na 32)	T76 (Pa 35 × Na 31)
T63 (Pa 35 × Na 32)	T79 (Na 32 × Pa 7)
T65 (Pa 7 × I.M.C. 47)	T82 (Na 32 × Pa 35)
T72 (Na 32 × I.M.C. 60)	T85 (I.M.C. 60 × Na 34)
T73 (Na 33 × I.M.C. 60)	T87 (I.M.C. 60 × Na 34)

(Pa = Parinari; Na = Nanay; I.M.C. = Iquitos)

The Departmental plots have only been in bearing for a short period, but indications are that the F2 generation retains the vigour shown by the parents at Tafo. It is clear from early yields that there is a variation between types in their response to environment.

Breeding programme.—The principal factor required from the introductions was that of virus resistance. The search for a virus-resistant cacao has been described by Posnette and Todd [10]. More recent

studies of the rates of multiplication of virus in various cacao types (Tinsley, unpublished) gave some evidence that, with at least two strains, the Iquitos cacao was the most resistant to virus multiplication. Further, the virus symptoms within the type were milder. As a result the search for a virus-resistant cacao is now concentrated within the Iquitos population, but as yet no immunity to infection has been found although there is tolerance and there are indications of resistance. The harbouring of a virulent virus without showing symptoms would be most undesirable.

Certain types appear to suffer less black-pod damage (*Phytophthora palmivora* Butl.) than do their neighbours within the 'Introductions' area at Tafo. Some of the Ecuador, Costa Rica, Surinam, and Iquitos types have been relatively free of black pod, but none of them sufficiently so to justify the type as a whole being regarded as resistant. Within any one type some trees have escaped black pod, but, until laboratory techniques are available for testing resistance, field observations can form the only basis for selection. Similarly a suitable technique for testing resistance to capsid damage has not yet been perfected.

Of more immediate importance to the breeding programme has been the high yield and early bearing of some of the trees. From among these have been selected those with large beans and a compact habit of growth. For some years there has been considerable variance of opinion concerning the quality factor, but most types of value to the breeding programme have now been accepted on quality by the manufacturers in the U.K. and U.S.A.

It has been the aim in producing new varieties to utilize hybrid vigour. The Upper Amazon types are naturally outcrossed (all are self-incompatible), as opposed to the West African Amelonado types which are all self-compatible. The greater vigour of the Upper Amazons might be attributable to the breeding system. Two new progeny trials have been planted at Tafo which contain a number of wide and close crosses between and within the introductions and local types. These trials have given further evidence of hybrid vigour and of the loss of vigour on selfing in cacao. In the Eighth Progeny Trial which was planted in 1952 the most vigorous varieties are those which have resulted from crosses between Upper Amazon and local selections. The first pods from this trial were harvested when the trees were 2 years old. With one of the selections that has come into bearing, an analysis of bean weight indicates that the factor for large bean size of the Iquitos parent is present. It is also apparent that where crosses were made between parents having a compact habit of growth the progeny are lower and more spreading than other selections. Two series of trials have been planned in different regions of the Gold Coast to show, in the first series, how the various cacao types and, in the second series, how the new varieties from the recent Progeny Trials at Tafo react under different soil and climatic conditions.

At the present time distribution to the farmer of planting material is made by seed or bare-root seedlings, but the time must come when it will be possible to educate the peasant farmer to use vegetative cuttings

TABLE 1. *Average Yields of Introduced Cacao Types and Hybrids*

Type	4th year	5th year		6th year		7th year		8th year		9th year		10th year	
	Pods/ stand	Pods/ stand	Wet wt. gm./pod	Pods/ stand	Wet wt. gm./pod	Pods/ stand	Wet wt. gm./pod	Pods/ stand	Wt. wt. gm./pod	Pods/ stand	Wet wt. gm./pod	Pods/ stand	Wet wt. gm./pod
HEADWATER POPULATION, UPPER AMAZON:													
Scavina T12	0·7	9·71	110·1	33·88	87·9	48·08	95·1	62·33	93·3	50·0	86·2	45·0	107·0
Nanay T61	0·07	4·19	83·3	15·74	88·1	27·30	85·9	48·07	84·3	57·78	90·6	39·7	93·7
Parinari T86	..	4·24	108·9	20·14	85·2	34·00	92·4	47·14	86·8	37·95	96·4	29·2	106·9
Nanay × Parinari T79	0·39	9·75	95·6	32·18	93·2	58·32	98·3	76·59	82·2	77·45	96·4	55·2	98·9
Iquitos T17	0·03	2·40	134·0	9·41	143·2	14·37	140·4	22·35	184·3	21·62	163·0	18·78	152·4
Nanay × Iquitos T72	0·04	3·91	109·4	14·17	107·6	20·69	117·4	32·39	125·4	43·57	121·2	31·2	133·6
Parinari × Iquitos T65	0·06	4·53	112·3	12·18	96·9	27·13	115·5	33·25	112·5	24·75	114·9	21·1	116·9
Morana × (?) T55	..	1·72	91·5	7·11	101·2	11·88	91·5	28·05	89·9	22·33	110·9	33·66	96·2
ECUADOR POPULATION:													
Icta E1 T3	..	2·94	104·7	10·81	109·1	26·28	101·2	37·78	100·8	38·50	113·9	38·28	104·7
M236 T77	..	..	..	..	..	0·06	..	..	..	0·13	..	1·0	..
M234 T78	..	..	..	..	..	..	..	..	..	3·0	..	2·7	105·0
CRIOLLO POPULATION:													
Nicaraguan: T27	..	0·03	..	0·13	..	1·03	123·2	2·13	153·0	3·4	153·0	3·23	187·0
Venezuelan: T28	..	..	..	1·14	126·2	10·24	109·9	19·6	119·1	20·14	120·0	13·61	143·0
ICS 85: T66	..	..	..	..	..	0·58	60·0	5·91	88·8	4·83	90·0	2·75	96·8
TRINITARIO POPULATION:													
'Wild' Tobago T5	..	0·50	115·0	2·4	76·5	12·4	77·6	17·6	84·2	14·5	101·9	13·9	72·6
Wild Trinidad T38	..	..	..	..	..	0·06	55·0	0·06	..	0·56	120·0	0·3	113·2
Costa Rica Green T8	..	0·06	220·0	0·61	220·0	4·27	143·4	6·34	138·9	7·69	170·0	5·61	152·3
Costa Rica Red T9	..	4·44	103·7	21·27	101·6	27·88	105·7	22·66	107·3	19·44	119·6	18·55	110·4
LOWER AMAZON AND AMELONADO POPULATION:													
Maranhao T6	..	1·19	120·0	12·18	98·5	24·13	100·9	25·31	99·7	23·50	107·0	24·81	106·8
Surinam T7	..	0·19	147·5	5·06	131·9	14·81	151·2	22·0	131·1	25·44	152·9	22·63	145·9
Amelonado A164	..	1·7	112·5	6·4	110·3	12·86	105·7	16·2	90·8	15·9	112·0	13·3	96·1

as planting material. It is known that cuttings of Upper Amazon types root easily and grow vigorously, and a Third Clonal Trial is being laid down at Tafo consisting of cuttings from Upper Amazon trees.

Yield.—Owing to the small and variable number of seedlings available for planting of any one 'T' type, it was not possible to adopt a statistical layout. The total number of trees within any one 'T' number varied from thirty to fifty. The computation of yield figures must be subject to all the faults of a non-statistical layout, but the 'Introductions' are of such importance that some yield estimate must be made. Each type was

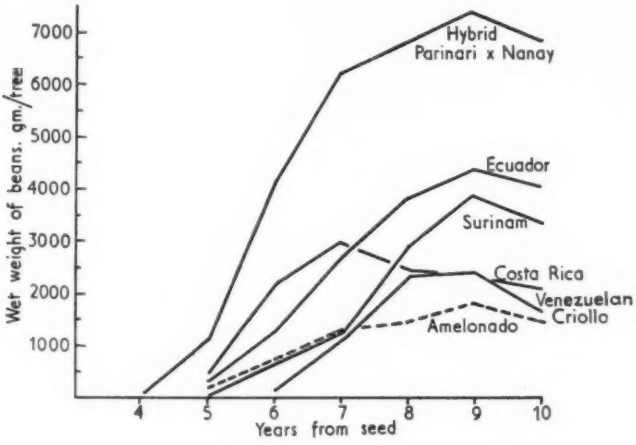

FIG. 1

planted at 14 ft. spacing, but it is not known if this is their optimum. The average yields of the introduced and other types are given in Table 1.

The variation in yield between the introduced population groups is illustrated by Fig. 1. When the average wet weight of beans per tree was calculated the total number of trees in any one type was used and not the number in bearing. This gives a truer picture of the yield to be expected from an area of cocoa larger than that at Tafo. The average number of pods per tree in Table 1 was calculated on a similar basis.

From Fig. 1 it can be seen that the yield per tree of the hybrid types in the Upper Amazon group was considerably greater than that of the other populations. The superiority of the hybrid Upper Amazon to that of its parents is illustrated in Fig. 2. The Upper Amazon types were earlier bearing and built up yield more rapidly, as is illustrated by the slope of the lines in Figs. 1 and 2. Only the best Ecuador type has been included in Fig. 1. The poor performance of the remaining types is shown in Table 1.

It will be noticed that the yield of all groups fell off at the tenth year. This was in common with the yields from the adjacent regions of the

Gold Coast, and was most probably due to a climatic effect rather than an inherent character.

From the yield records for individual cacao types in the various population groups, given in Table 1, the yield of dry cocoa per acre can be calculated: the wet weight of cocoa per tree is obtained by multiplying the number of pods per tree by the average wet weight of a pod (adjacent columns), and at 14-ft. spacing, 1,000 gm. wet weight of pods per tree gives approximately 200 lb. of dry cocoa per acre.

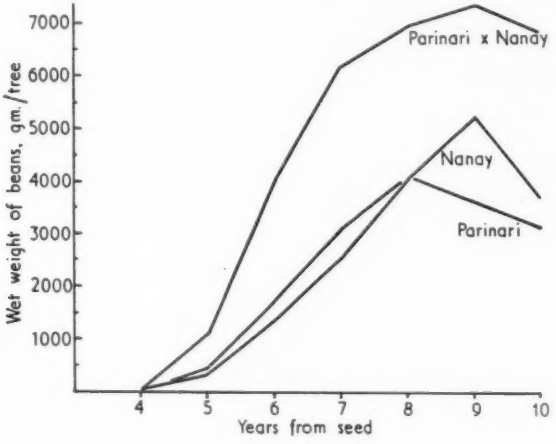

FIG. 2

The figures in Table 1 are for trees spaced at 14-ft. intervals. The earlier extension plots were planted at 10-ft. and 12-ft. spacing, but the Department of Agriculture now recommend 8-ft. spacing. There is still not enough information to say which is the optimum spacing for any one area. It is difficult to compare the yields of the Department of Agriculture, Gold Coast, plots with those at Tafo because the former are in their very early years of bearing. The influence of capsid damage and shade management on yield is comparatively great in the early years. On the whole the distribution of pod classes within any one Upper Amazon type is normal at Tafo, but present indications are that the pod-class distribution in the F2 generation on Department Plots approaches the very skew distribution found in West African cacao. Environmental effect contributes more than the inherent effect of the generation to this skewness. It is also apparent that the relative performance of selections varies according to soil and climatic conditions, but further annual yield figures will be required before the picture is clear. On the whole the yield figures from Department plots for the first 2 years of bearing are lower than those from the W.A.C.R.I. plot at a corresponding age.

Bean characters.—To the chocolate manufacturer small beans are undesirable, and on that account some of the higher-yielding Upper

Amazons have been considered unsuitable. The smallest beans are found in the Nanay (T61, T62, T92), Parinari (T86), and Scavina (T12) types, and consequently these have not been recommended for distribution as seed to the West African farmer. However, a selection from the Scavina type has been included in the Eighth Progeny Trial, as it has been reported from Trinidad to be resistant to witches' broom disease [11]. This may prove useful if the disease ever reaches West Africa.

The largest beans are those of the Iquitos type, which surpass the dry-weight standard of 1 gramme per bean suggested as a breeding minimum in the Appendix on Cocoa Breeding in West Africa, at the

TABLE 2. *Bean Sizes of Introduced Cacao Types and Hybrids*

Type	*Average weight dry bean gm.*	*Beans/lb. (wet wt.)*	*Type*	*Average weight dry bean gm.*	*Beans/lb. (wet wt.)*
			Parinari ×		
Nanay T61	0·91	206	Iquitos T65	0·95	178
,, T62	0·90	199	Scavina T12	0·97	177
,, T92	0·90	183	Maranhao T6	1·02	169
,, T81	1·02	178	Surinam T7	1·54	118
Parinari T86	0·89	182	Ecuador T3	..	154
,, T30	0·95	193	Wild Tobago T5	..	191
Nanay ×			Costa Rica T8	..	115
Parinari T60	0·95	189	,, ,, T9	1·50	139
,, T63	1·08	174	Criollo T27	..	103
,, T76	1·03	166	,, T28	..	118
,, T79	0·91	187	,, T66	..	141
Iquitos T17	1·14	140	WAA	1·07	165
Morona T55	0·87	183			
Nanay ×					
Iquitos T72	1·12	157			
,, T85	1·08	159			
,, T73	0·95	175			
,, T90	1·18	156			

Cocoa Conference of 1947 [12]. The Nanay-crossed Iquitos types have beans larger than the Nanay but smaller than Iquitos. The Parinari × Iquitos cross has a larger bean than the pure Parinari. The manufacturers have reported on bean size [13], and some of the approved types do not attain the desired 1 gramme per bean (see Table 2).

The percentage of shell per bean represents a source of wastage in the factory processing. Some of the introductions have as much as 2 per cent. more shell than the average West African Amelonado. Although shell percentages vary from one sample to another, it would appear that a mixed sample of Upper Amazon beans can be expected to average 1 per cent. more shell than West African Amelonado. Cocoa-butter estimates made at intervals over the period 1947–53 have varied both between and within types. It is unlikely that a bulk sample of types approved for distribution as seed will differ to any significant extent from an average West African Amelonado sample. This applies not only to the cocoa butter but also to the caffeine, theobromine, and free-fatty-acid content.

B: Theobroma and Herrania Species

Seven other Theobroma species and two species of Herrania were introduced at the same time as the *T. cacao* types. The following were introduced (there is still some doubt as to the correct classification of the Herrania species):

Theobroma grandiflora K. Schum.	(T33) from Para, Brazil.
T. speciosa Spreng.	(T104) ,, ,, ,,
T. subincana Mart.	(T105) ,, ,, ,,
T. microcarpa Mart.	(T108, T109) ,, ,, ,,
T. obovata	(T119) ,, ,, ,,
T. angustifolia D.C.	(T121) from Dominica.
T. bicolor (Humb. et Bonpl.)	
Herrania balaensis (?)	(T35) from St. Augustine, Trinidad.
	(T58) from Botanic Garden, Port of Spain.
	(T59) from St. Augustine.
H. mariae (?)	(T67) from Belem (Para), Brazil.
	(T68) ,, ,, ,,
	(T69) ,, ,, ,,

Each species is represented by a limited number of stands, and as little is known of the optimum shade conditions there has been a tendency to overshade the trees which might have modified their performance. As with the *T. cacao* introductions, the spacing has been 14 ft. × 14 ft. Details of performance are given in Tables 3 and 4.

TABLE 3. *Properties of Cocoa from Introduced Theobroma Species*

Species	*No. of beans/pod (average)*	*Av. wet wt./pod gm.*	*Butter fat*	*Alkaloids*	*Theobromine*	*Caffeine*	*Free fatty acids*
			%				%
T. grandiflora .	32·7	411·7	60·5	nil	nil	nil	0·41
T. speciosa . .	14·9	36·6	26·8	nil	nil	nil	1·30
T. microcarpa .	12·7	32·3	6·2	trace	..	..	4·38
T. bicolor . .	34·0	104·4	55·0	nil	nil	nil	0·53

Of the *T. grandiflora* introduction fourteen trees survive at Tafo. The first natural set occurred in 1951 when the trees were 7 years old. Since then less than ten natural sets have developed, and there is considerable seasonal variation between stands in the time and degree of flowering. Ten trees survive at Tafo of the *T. speciosa* introduction. Flowering did not occur until 1952, in which year the first pods (hand-pollinated) were harvested. Cuttings of *T. speciosa*, like those of *T. grandiflora* and *T. microcarpa*, did not survive in the field for more than 2 years, having failed to produce a leading shoot. It is of interest that some of the cuttings of *T. speciosa* produced flowers on the branches, whereas the seedling tree only bears flowers on the trunk. Ten trees

survive of *T. microcarpa* from the original introduction of four pods, but although flowering commenced in 1950 there were no natural sets until 1954. No sets either natural or hand-pollinated have been obtained on the eleven trees of *T. angustifolia*.

Observations have been made on the susceptibility of the species to black pod disease and cocoa swollen-shoot virus. All the Herrania species and *T. microcarpa* have shown natural infection by black pod. Although *T. speciosa* has not been naturally infected in the field it was possible to infect undamaged pods by spraying with a spore suspension. All the species have now been tested for resistance to virus infection, some to as many as eight different strains. All have been found susceptible (T. W. Tinsley, private communication).

First crosses between Gold Coast selections and other species were

TABLE 4. *Average Yields of Herrania Species and Types*

Species and type	*6th year* Pods/ stand	*7th year* Pods/ stand	*8th year* Pods/ stand	*9th year* Pods/ stand	*9th year* Wet wt. gm./pod	*10th year* Pods/ stand	*10th year* Wet wt. gm./pod	*Average No. of* beans/pod
H. balaensis (?) T35	0·40	1·40	2·70	4·80	8·87	3·10	10·45	25·5
H. balaensis (?) T58	0·29	2·07	4·36	5·28	8·18	5·86	10·55	24·3
H. balaensis (?) T59	1·37	4·12	5·25	8·00	9·33	3·38	16·12	27·2
H. mariae (?) T67	2·07	6·73	18·76	28·11	14·28	22·92	14·28	23·3
H. mariae (?) T68	2·60	5·60	8·40	15·80	11·31	9·60	14·19	15·7
H. mariae (?) T69	4·75	6·75	10·62	11·75	12·10	13·50	13·69	15·4

made in 1950–1. Since that time a large number of hand pollinations have been made between various *T. cacao* types and other Theobroma species. A low percentage of sets has been obtained and many of the beans in the resulting pods have failed to develop cotyledons and embryo. These beans are often plump but contain nothing but a jelly-like substance. During the 1953 season the cross Upper Amazon cacao × *T. grandiflora* was more successful than Upper Amazon × *T. speciosa*. Seventy-three per cent. of the former pollinations were successful and only 21 per cent. of the latter. In both crosses three-quarters of the beans in a pod were flat.

All the good beans were planted, and some of the resulting seedlings were selected for the induction of polyploidy. Approximately 80 per cent. of the untreated beans germinated but died either before or when the first leaves were formed.

From among the beans of several of the crosses have developed seedlings with all the superficial characteristics of the *T. cacao* parent. They do not resemble the seedlings that died at the three- or four-leaf stage. Their origin is still in doubt, as all the pollinations were with flowers protected from insect visitation and the majority of the cacao parents were self-incompatible. These seedlings have been planted in the field for further study.

Summary and Conclusions

During the last 10 years, various types of *Theobroma cacao* and related species from South America have been introduced to the Gold Coast. The characters and performance of these introductions and their progeny are reviewed.

It is evident that these recent introductions from South America will, within the next two decades, have a considerable effect on cocoa production in the Gold Coast. The interest shown by the peasant farmers in the new types makes it certain that the bulk of the new plantings will be made from seed of the ten approved types. As the Department of Agriculture issues bare-root seedlings only to farmers who have lined and pegged their holdings, it is to be hoped that a higher standard of husbandry will be practised with the new plantings.

The issue of the approved types should be looked upon as an interim measure until new approved varieties resulting from the breeding programme are available. The initial observations in the new progeny trials at the West African Cacao Research Institute give promising indications that still better varieties can be expected within the next 10 years. Because local selections in clonal trials have a high early yield, it is hoped that both the 1944 introductions and any new types resulting from the breeding programme will be used as clones.

It is apparent that the results obtained from the 1944 introductions justify a further introduction of types not present at W.A.C.R.I. from Pound's collection in Trinidad.

Acknowledgements.—Our thanks are due to the Director of Agriculture, Gold Coast, and the Officers of the Cocoa Division for their co-operation in supplying information and help in the field. This paper is published by kind permission of the Acting Director of Cacao Research.

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(*Received 22 February 1955*)

THE INFLUENCE OF NITROGEN, PHOSPHATE, POTASH, AND LIME ON THE SECRETION OF NECTAR BY RED CLOVER IN THE FIELD

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SAND-CULTURE experiments were carried out in 1951 and 1952 to examine the influence of nitrogen, phosphate, and potash on the secretion of nectar by various species of flowering plants, in particular by red clover [1]. Certain conclusions were drawn from the results, but before practical recommendations could be based upon them it was necessary to do similar experiments in the field, since there the conditions of plant growth are in many ways different from those in pot experiments. For this reason a field experiment on micro-plots was carried out in 1953.

Methods.—A strip of level ground was divided into sixty-four plots, 9 × 6 ft. each, separated by grass paths 2 ft. wide, there being three rows of eight and three rows of fourteen (including two spare) plots. The soil was clay-with-flints, with a fairly solid pan of stones at a depth of about 7 in. Soil samples were taken at twelve points and tested for pH and potash content. There was a slight pH gradient from one end of the strip to the other, ranging from 6·6 to 7·1 in the topsoil and 6·1 to 7·0 in the subsoil, there being therefore no indication of lime deficiency. The potash content, determined by the 0·5 N acetic-acid-extraction method, varied from 6 to 9 mg. per 100 g. of soil. The phosphate status of the field was known to be low by Rothamsted standards, and there was no record of phosphate dressings having been applied to this strip in recent years. However, on this field phosphate dressings do not greatly increase the yield of normally responsive crops such as barley and potatoes.

There were three Sections within the strip. Section X consisted of twenty-four plots which were sown with red clover in March 1952, mown at the end of the summer, and top-dressed with the fertilizers in March 1953. Section Y consisted of twenty-four plots sown in March 1953, the fertilizers being applied 2 days later. There were twelve duplicated treatments in each Section, namely the various combinations of N_0 and N_1, P_0 and P_1, and K_0, K_1, and K_2. The dressings given were, in cwt./acre: sulphate of ammonia, 2; superphosphate, 4; muriate of potash 1½ and 3: equivalent to N, 0·4; P_2O_5, 0·72; and K_2O, 0·75 and 1·5 cwt/acre. The fertilizers were broadcast and, on Section Y, raked in by hand. The remaining sixteen plots, Section Z, were sown in March 1953 and dressed with potash and lime 2 days later. There were four replicates of the treatments, O, K, L, and KL, the dressings being muriate of potash 2 cwt./acre (1 cwt. K_2O/acre), and calcium hydroxide 30 cwt./acre.

The clover variety used was late-flowering Montgomery (New Zealand Certified Mother Seed). It was broadcast thickly to ensure a good take, as the plots were only raked after sowing, but germination was good and as a result the stand was rather dense. The plots were hand-weeded

[Empire Journ. of Exper. Agric., Vol. 23, No. 90, 1955]

several times; no thinning was done but by the end of the season the plants had effectively thinned themselves.

On each plot five or six flower heads that were about to open were covered with muslin to exclude insects a week before each sampling day. It was found impossible to employ the sampling method used in the pot experiments (cutting each floret off where the petals join together and then probing the corolla tube with a glass pipette), as the florets had narrower corolla tubes than those of the varieties used in 1951 and 1952. Instead, each floret was pulled out of its calyx and the drop of nectar was extracted from the lower end. This proved efficient and was probably equally accurate; moreover, it could be seen at once when a floret contained a weevil larva (*Apion apricans* Herbst.)—as many did on the earlier-flowering section X. The first five times Section X was sampled, two heads were used from every plot to provide two separate samples, each collected from thirty florets. From these results the variation within the plots could be determined. This was found to be greater than the variation between plots, and subsequently a single sample was taken on each plot, ten florets from each of three heads being used. It was not possible to sample a larger number of heads owing to the labour involved in covering them with muslin. Heads from six plots at a time were collected and put in 4×1 in. specimen tubes to be sampled in the laboratory. The maximum time the heads remained in the tubes was 45 minutes and generally it was less. The order of sampling the different plots was changed on each occasion to minimize any differences due to the time of day. The method of determining the mean yield of sugar per floret from each sample was the same as that used previously [1].

As the pot experiments had indicated that the effects of specific fertilizer treatments on nectar yields should be considered only in conjunction with their effects on vegetative growth, information on growth rates and total growth was necessary. The internodes of four tagged shoots on each plot were counted weekly. Unfortunately, owing to the wet season, the stems were lank and soft and there was much scorch disease, due to *Kabatiella caulivora*; this produces elongated lesions on the stems which break very easily. Consequently, frequent substitution of new tagged shoots was necessary on all plots and the figures on growth rate are not as reliable as one would wish. 'Relative growth rates' were calculated from the internode counts in the same way as in the previous paper. Weekly counts were made of the number of heads per plot. For the first few weeks the total number was counted and then, when that became too large, six randomized patches, each 1 ft. square, were counted on each plot. On 5 October the two Sections sown in 1953 were cut and the tops weighed; since it was the end of the season and the plants were beginning to die back, these weights are only approximate. The plants in Section X had died back too far for cutting and weighing to be possible.

Results

The mean nectar yields of all plots in Section X showed little variation during the 7 weeks' flowering period, ranging from 0·135 to 0·176 mg. sugar per floret. The mean yields from both Sections Y and Z varied

therefore be expected to resemble those obtained from the former Section rather than from the latter. The field results showed that while potash produced no consistent effect on growth on Section X, it tended to increase the nectar yield there. (The increase due to phosphate had no parallel in the pot experiments.) On Sections Y and Z potash markedly increased total growth and also markedly decreased nectar yield [cf. 2]. Evidently the stage of development of the plant should be taken into consideration in any further work on the influence of fertilizers on nectar production. The responses of 2-year-old plants are, of course, most relevant to normal farming practice.

The influence of nitrogen on growth and nectar secretion in both Section X and Section Y was relatively slight, in agreement both with expectation and with the results of the pot experiments. The positive effect of lime on nectar yield (Section Z) should be noted since this mineral was not tested in the earlier pot experiments. It is particularly interesting because the soil analysis did not suggest that the ground was lime-deficient and the lime did not affect the growth of the plants. Beekeepers have observed that good honey-flows are often associated with calcareous soils, and Oertel [3] recommended liming to improve honey yields from clover and lucerne. Information is needed about the effect of lime dressings on nectar yield in the second year of growth.

Summary

Field experiments with micro-plots of red clover are described. They were designed to test the effects of nitrogen, phosphate, and potash fertilizers, and lime, on the secretion of nectar by plants sown (*a*) in the previous year and (*b*) in the same year as that in which the fertilizers were applied. Measurements of both nectar yield and plant growth were made.

Neither the growth nor the production of nectar was significantly altered by phosphate or potash on the second-year plots, nor had phosphate much influence on the growth of the first-year plots. (The initial phosphate content of the soil was adequate.) Potash significantly increased total growth and significantly decreased nectar production on the first-year plots. These results are discussed in relation to previous work. It is suggested that the contrast between the responses of the two sets of plots may be related to the maturity of the plants. Nitrogen had little influence on growth and none on nectar in either set of plots.

Lime increased the nectar production of first-year plots, although it did not affect the growth of the plants, and this in spite of the fact that the initial pH of the soil was fairly high.

Acknowledgements.—We are indebted to R. G. Warren for the soil analyses, to Joyce White for assisting in the sampling work, and especially to Emily P. Simpson for help in the design of the experiment and the analysis of the results.

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(*Received 26 October 1954; as revised, 14 March 1955*)

THE YIELD AND COMPOSITION OF MIXED CEREAL-LEGUME CROPS AT DIFFERENT STAGES OF GROWTH PART I

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CONSIDERABLE work has been carried out with mixed cereal and legume crops in the eastern areas of the country [1, 2, 3] but little information is available about the productivity of such mixtures under the higher rainfall conditions of the west.

The following experimental results were obtained from an investigation, located near Aberystwyth on the western seaboard, into the productivity of these crops when at a suitable stage for ensilage and when allowed to ripen and harvested as grain and straw. To determine the relative production of the cereal-legume mixture the crops with which it was compared were pure stands of oats, peas, and field beans. The

TABLE 1. *Distribution of Rainfall throughout the Six Months March–August (inches)*

	1949	*1950*	*1951*
March–April . .	6·47	5·25	7·93
May–June . . .	4·55	3·49	3·11
July–August . .	3·97	11·40	9·35
Seasonal total . . .	14·99	20·14	20·39
Annual total . .	40·87	49·02	44·55

crops were grown on the same farm, on soils of the Penrhyn and Gwern series of similar medium fertility. Each year the experiment was laid down in a different field but occupied the same place in the rotation, being immediately preceded by a short-term ley. Over the experimental period the mean annual rainfall in the locality was 44·81 inches.

From Table 1 it can be seen that although there was marked fluctuation in the rainfall from one year to another, in every season there was ample supply of moisture during the period of plant growth; and with the relatively mild coastal temperature, climatic conditions were ideal for rapid vegetative growth. In two of the three seasons, however, rainfall during the late summer was too heavy for ideal ripening and harvesting.

Experimental method.—During the three years of the experiment a complete fertilizer (12 per cent. N, 12 per cent. P_2O_5, and 15 per cent. K_2O) was applied annually to all the crops at the rate of 2 cwt. per acre. The seeding rates were, per acre: 1½ cwt. S. 84 oats; 1½ cwt. Marathon Maple peas; 2 cwt. spring beans; and 2 cwt. of mixture containing 50 per cent. oats, 25 per cent. peas, and 25 per cent beans.

[Empire Journ. of Exper. Agric., Vol. 23, No. 90, 1955]

Each year a randomized block layout was used, with fourfold replication of the four variables, oats, peas, beans, and mixture. Samples from the four crops were taken regularly throughout the growing period and at similar stages of growth each season. At every sampling stage cuts were taken at random points from each of the sixteen plots, so that for every crop there were four replication samples. The area cut for each

TABLE 2. *Stages of Growth at which Samples Were Taken*

Stage	*Oats*	*Peas*	*Beans*
1	Vegetative stage; height about 1 ft.	Full vegetative condition.	Height only about 10 in., but some plants showing immature buds.
2	Pre-shooting.	Earliest of plants coming into flower. Majority carrying flower buds.	In full flower.
3	In full head but dark green in colour.	In full flower. Some plants with small immature pods.	Still showing flowers on upper parts of stem, but pods forming on lower stem.
4	Grain soft and milky, showing only slight yellowing. Yellow colour of straw beginning to predominate over green.	Earliest pods forming seeds but some still undeveloped. Foliage still dark green in colour.	Seeds formed in most forward of pods, but foliage still dark green.
5	Grain soft but fully formed. Lower portion of straw yellow.	Full seeds in all but latest of pods. Foliage has lost dark-green colour.	Seeds soft but well developed. Pods and foliage retaining green colour.
6	Grain soft but fully formed. Lower portion of straw yellow.	Seeds soft but fully developed. Irregular ripening of foliage.	Beans on lower stems fully developed and beginning to dry out.
7	Ripe.	Majority of seeds and pods brown in colour, but foliage still showing traces of green.	Majority of seeds carrying brown scar and ready for harvesting, but foliage still showing appreciable amount of green.

sample was 8 sq. yds., and to ensure accuracy in measuring a steel frame of this area was used. As the samples were taken from areas within the plots, border effects were eliminated.

The sample areas were cut by hand clippers and the material was weighed immediately after cutting. A representative sample was then taken for chemical analysis so that the percentage of dry matter could be related directly to the stage of growth of the crops. As far as possible the samples were taken when the crop plants were free from superficial moisture. After the oat-legume mixture had been weighed and sampled it was divided into its three constituents and these were also weighed and sampled for analysis.

Each season the crops were cut at seven different stages of growth

(Table 2). No reference is made to the mixture of oats, peas, and beans in Table 2, because on the whole the constituents of the mixture were at the same stages of growth as the pure crops; but, particularly in 1949, the oats in the mixture retained their green colour to a greater extent and were 3–4 days later in ripening than in the pure crop. The peas and beans, on the other hand, appeared to be slightly quicker-maturing in the mixture than in the pure crops.

The dates of sowing and sampling the plots are given in Table 3.

TABLE 3. *Sowing and Sampling Dates of the Experimental Plots*

Dates of sowing		
1949	*1950*	*1951*
24 March	15 March	19 April

Dates of sampling			
Stage	*1949*	*1950*	*1951*
1	..	6 June	18 June
2	20 June	20 June	28 June
3	1 July	29 June	17 July
4	12 July	17 July	1 Aug.
5	19 July	25 July	8 Aug.
6	26 July	1 Aug.	14 Aug.
7	2 Aug.	10 Aug.	21 Aug.

Experimental Results

1. *Variations in the Yield and Composition of the Four Crops at Different Stages of Growth (Tables 4 and 5)*

Oats.—The percentage of dry matter showed a regular increase throughout the sampling period in each season. There was also a regular increase in the dry-matter yield of the oats until the final sampling stages. The percentage of crude protein in the dry matter of the oats showed a marked decrease throughout the initial sampling stages, until in the last stages of ripening it remained more or less constant. Up to the 5th sampling stage in 1949 and 1950 and the 4th sampling stage in 1951 there was an increase in the yield of crude protein.

Peas.—The percentage of dry matter in the crop showed a regular increase throughout the sampling period, as did the dry-matter yield, but there was no significant difference between yields at the penultimate and final sampling stages in any season. Though the percentage of crude protein in the dry matter of the peas showed a significant decrease throughout the growing and ripening period, in the seasons 1949 and 1950 it appeared to remain practically constant over the last four sampling stages. In each season the yield of crude protein appeared to reach a maximum at the 5th–6th stages, although only in 1951 was the decrease in yield at the final sampling stage statistically significant.

TABLE 4. *The Percentage of Dry Matter and Crude Protein in the Four Crops at Different Stages of Growth*

	Stage	1 D.M.	1 C.P.*	2 D.M.	2 C.P.	3 D.M.	3 C.P.	4 D.M.	4 C.P.	5 D.M.	5 C.P.	6 D.M.	6 C.P.	7 D.M.	7 C.P.	Mean D.M.	Mean C.P.	S.E.± D.M.	S.E.± C.P.
Oats	1949	..	..	22·2	9·69	25·4	7·64	33·3	6·88	37·3	6·35	43·5	6·20	52·2	6·20	35·7	7·16	0·55	0·190
	1950	17·4	18·23	18·9	12·83	20·8	11·30	27·8	8·84	39·9	8·66	43·5	8·21	55·0	8·33	31·9	10·92	1·15	0·376
	1951	16·2	19·92	17·1	15·41	21·9	8·86	27·9	7·41	32·6	7·19	39·8	6·98	44·5	7·01	28·6	10·40	0·83	0·763
	Average	16·8	19·08	19·4	12·64	22·7	9·27	29·7	7·71	36·6	7·40	42·3	7·13	50·6	7·18	31·1	9·49	1·38	0·707
Peas	1949	..	..	11·8	24·62	13·4	23·34	17·0	20·10	18·4	20·13	26·3	19·60	34·7	18·84	20·3	21·04	0·50	0·692
	1950	14·2	27·13	15·3	23·16	16·0	21·85	18·4	21·34	21·4	20·61	27·0	20·76	32·2	20·07	20·6	22·13	1·19	N.S.
	1951	14·1	23·00	12·1	21·99	13·0	21·62	13·8	20·79	15·9	19·78	18·4	18·63	27·6	17·49	16·4	20·47	0·77	0·689
	Average	14·2	25·07	13·1	23·26	14·1	22·27	16·4	20·74	18·6	20·17	23·9	19·66	31·5	18·80	18·8	21·42	0·68	0·532
Beans	1949	..	..	11·4	24·96	15·4	19·31	18·2	18·01	18·4	17·43	21·7	17·49	23·8	16·70	18·2	18·98	0·39	0·938
	1950	12·3	29·65	14·5	24·04	14·3	23·12	17·1	21·08	21·1	21·34	22·5	20·88	24·7	20·03	18·1	22·88	0·79	0·644
	1951	11·4	26·05	12·1	24·89	13·2	19·64	14·7	20·11	16·2	19·07	17·2	18·30	19·3	18·00	14·8	20·98	0·53	0·819
	Average	11·9	27·85	12·7	24·63	14·3	20·69	16·7	19·73	18·6	19·28	20·5	18·89	22·6	18·24	16·7	21·33	0·76	0·624
Mixture	1949	..	..	14·7	16·02	21·5	14·91	22·7	13·39	27·1	12·73	34·7	11·31	42·2	10·40	27·1	13·13	0·77	0·816
	1950	15·9	21·79	21·0	14·85	18·8	14·79	25·8	13·74	30·9	13·50	35·9	13·29	44·4	13·40	27·5	15·06	0·76	0·541
	1951	15·1	21·51	13·3	16·31	20·4	10·67	25·4	9·98	27·6	9·38	35·2	9·54	38·1	9·13	25·0	12·36	0·82	0·297
	Average	15·5	21·65	16·3	15·73	20·2	13·46	24·6	12·37	28·5	11·87	35·3	11·38	41·6	10·98	26·5	13·92	1·16	0·755

* In these and subsequent tables, D.M. = dry matter and C.P. = crude protein (per cent. of D.M.).

TABLE 5. *The Yield of Dry Matter and Crude Protein in the Four Crops at Different Stages of Growth (cwt. per acre)*

	Stage	1 D.M.	1 C.P.	2 D.M.	2 C.P.	3 D.M.	3 C.P.	4 D.M.	4 C.P.	5 D.M.	5 C.P.	6 D.M.	6 C.P.	7 D.M.	7 C.P.	Mean D.M.	Mean C.P.	S.E.± D.M.	S.E.± C.P.
Oats	1949	..	..	19·1	1·85	25·1	1·92	36·0	2·48	39·3	2·49	40·0	2·48	39·6	2·45	33·2	2·28	1·99	0·151
	1950	15·0	2·73	29·0	3·72	34·6	3·93	50·0	4·43	56·1	4·85	59·3	4·87	57·7	4·78	43·1	4·19	2·71	0·298
	1951	15·7	3·12	28·3	4·36	57·1	5·03	69·0	5·11	69·8	5·02	70·5	4·92	72·0	5·05	54·6	4·66	2·15	0·167
	Average	15·4	2·93	25·5	3·31	38·9	3·63	51·7	4·01	55·1	4·12	56·6	4·09	56·4	4·09	42·7	3·74	4·20	N.S.
Peas	1949	..	..	28·7	7·06	33·3	7·77	52·0	10·45	53·5	10·77	52·3	10·27	51·6	9·74	45·3	9·34	2·30	0·504
	1950	9·6	2·61	25·6	5·94	35·2	7·71	50·3	10·77	51·8	10·59	54·0	11·19	54·3	10·92	40·1	8·53	2·81	0·660
	1951	8·3	1·91	15·6	3·42	39·6	8·04	50·8	10·55	54·7	10·83	56·5	10·52	53·7	9·40	39·9	7·89	1·80	0·395
	Average	9·0	2·26	23·3	5·47	36·0	7·84	51·0	10·59	53·3	10·73	54·3	10·66	53·2	10·02	40·0	8·22	2·93	0·445
Beans	1949	..	..	18·3	4·55	26·9	5·19	33·4	6·02	38·0	6·60	41·4	7·23	43·7	7·33	33·6	6·15	1·57	0·314
	1950	9·1	2·70	17·3	4·17	25·3	5·91	35·0	7·43	37·0	7·87	38·7	8·08	41·1	8·26	29·1	6·35	1·80	0·466
	1951	5·5	1·44	11·2	2·79	30·2	5·94	45·0	9·06	51·9	9·89	53·5	9·80	56·5	10·16	36·3	7·01	1·19	0·199
	Average	7·3	2·07	15·6	3·84	27·5	5·68	37·8	7·50	42·3	8·12	44·5	8·37	47·1	8·58	31·7	6·31	2·93	0·608
Mixture	1949	..	..	21·8	3·48	33·8	5·05	46·7	6·25	50·2	6·36	52·1	5·90	52·2	5·47	42·8	5·42	3·72	0·513
	1950	14·5	3·17	36·3	5·40	38·3	5·72	56·6	7·76	57·9	7·84	61·8	8·25	58·3	7·94	46·3	6·58	3·50	0·685
	1951	12·9	2·78	23·0	3·74	51·6	5·50	64·9	6·46	67·9	6·36	68·3	6·51	67·8	6·18	50·9	5·36	1·45	0·163
	Average	13·7	2·98	27·0	4·21	41·2	5·42	56·1	6·82	58·7	6·85	60·7	6·89	59·4	6·53	45·3	5·67	3·09	0·262

Beans.—Throughout the growing period the percentage of dry matter increased regularly each season, and there was a steady increase in the dry-matter yield of the beans until the final sampling stage. The percentage of crude protein in the dry matter of the beans showed a decrease which was significant in the initial sampling stages but not later. The increase in the yield of crude protein in the beans between consecutive sampling stages was small and not significant, being significant, however, between the first three and the final stages.

Mixture of Oats, Peas, and Beans.—The percentage of dry matter of the mixture increased regularly throughout the sampling period. There was a marked increase in the yield of dry matter until the 5th stage of sampling, and thereafter the yield remained more or less constant. The percentage of crude protein in the dry matter of the mixture showed a considerable fall until the 3rd–4th sampling stages; only in 1949 was there a statistically significant difference between the percentage of crude protein at the 4th and 7th sampling stages. In each season the yield of crude protein in the mixture appeared to reach a maximum some time before the final sampling stage, but although the apparent loss at the final sampling stage was considerable, in no case was it statistically significant.

2. *Comparison of the Four Crops in their Yields of Dry Matter and Crude Protein*

For reasons indicated later, the optimum stages of growth for cutting the four crops for ensilage have been assumed to be stages 3 and 4, and it is therefore of particular interest to consider the relative yields of the four crops at these stages.

The average annual yield of dry matter and crude protein of the four crops at stages 3 and 4 was as follows (cwt. per acre):

	Stage 3		*Stage 4*	
	D.M.	*C.P.*	*D.M.*	*C.P.*
Oats . .	38·9	3·63	51·7	4·01
Peas . .	36·0	7·84	51·0	10·59
Beans .	27·5	5·68	37·8	7·50
Mixture .	41·2	5·42	56·1	6·82

Over the 3 years of the experiment the highest average yield of dry matter was obtained from the mixture and the least yield was produced by the bean crop. Although the oats and peas showed marked seasonal differences, their average yields of dry matter were very similar. In terms of crude-protein yield, on the other hand, the pea crop throughout the experiment consistently gave the highest yield at both stages 3 and 4, while the oat crop was the lowest yielding. The beans and mixture showed no significant difference in their average crude-protein yield.

At stage 7, the ripe stage, the average annual yield of dry matter and

crude protein harvested from the grain of the four crops was as follows (cwt. per acre):

	D.M.	*C.P.*
Oats . .	21·5	2·65
Peas . .	13·0	3·66
Beans .	12·3	3·98
Mixture .	20·1	3·40

Over the 3 years the oat grain produced a similar yield of dry matter to the grain of the mixture, but a lower yield of crude protein. The legumes showed marked seasonal variations in their yield, and considerable difficulty was encountered under the conditions of the experiment in growing legumes for seed production.

With the mixture, in each season the percentage by weight of the constituents remained practically the same throughout the sampling period, the percentage of each at the initial sampling stages being almost the same as at the final stages. There was considerable variation in the percentage of each constituent from one season to another, yet in every season the oats gave the greatest and the beans the least contribution of

TABLE 6. *Percentage of Constituents in Mixture at Stage 3*

In terms of dry matter			
	Oats	*Peas*	*Beans*
1949 .	47	36	17
1950 .	69	19	12
1951 .	82	12	6
In terms of crude protein			
1949 .	30	49	21
1950 .	53	27	20
1951 .	73	18	9

dry matter. Because the percentage of crude protein was higher in the dry matter of the legumes than in that of the oats, the peas and beans contributed relatively more to the crude-protein yield than to the dry-matter yield of the mixture. Nevertheless, only in 1949 did the oats contribute less than half of the crude-protein yield of the mixture, while in 1951 they produced almost three times as much as the combined yield of the legume constituents (Table 6).

3. *Losses Incurred During the Curing and Harvesting of Oats and Legumes*

As previously indicated, samples were taken at each stage of growth to determine the dry matter and crude protein yielded at the time of cutting. In addition, at the later stages of growth, the cut plants after being weighed and sampled were dried under natural conditions and threshed. The resultant grain and straw were weighed and analysed, to give the

dry-matter and crude-protein yields. The grain and straw together were found to give considerably lower yields of dry matter and crude protein than were yielded by the corresponding fresh material at the time of cutting (Figs. 1 and 2). These differences indicate the losses incurred during curing and threshing: they are shown in Table 7 for the last three stages of ripening.

TABLE 7. *Losses Incurred During the Curing and Harvesting of Oats and Legumes (Average of 3 years; cwt. per acre)*

	Stage	Yield when cut		Loss during curing and threshing		Percentage loss	
		D.M.	C.P.	D.M.	C.P.	D.M.	C.P.
Oats	5	55·1	4·12	9·0	0·85	16·3	20·6
	6	56·6	4·09	9·0	0·73	15·9	17·8
	7	56·4	4·09	9·0	0·79	15·9	19·3
Peas	5	53·3	10·73	11·5	3·85	21·5	35·8
	6	54·3	10·66	8·0	3·34	14·7	31·3
	7	53·2	10·02	7·9	3·19	14·8	31·8
Beans	5	42·3	8·12	15·1	4·06	35·6	50·0
	6	44·5	8·37	13·0	3·54	29·2	42·3
	7	47·1	8·58	9·8	2·94	20·8	34·3
Mixture	5	58·7	6·85	10·9	2·21	18·5	32·2
	6	60·7	6·89	9·8	2·02	16·1	29·3
	7	59·4	6·53	8·5	1·78	14·3	27·2

At the three stages of growth there was a greater percentage loss of crude protein than of dry matter, indicating that it was in the protein-rich parts of the plant—leaves and seeds—that the shedding and other losses were most severe. It also appears that the crops varied in susceptibility to loss. In terms of crude protein the pea and bean crops showed the greatest percentage loss, while the oat crop showed the least.

In 1949, when harvesting conditions were good, the protein losses were lower than in the two subsequent seasons when there was heavy rainfall during the periods of harvesting. The losses were greatest in 1950, the season with the heaviest rainfall and the least sunshine during the month of August. The protein losses at stage 7 for the different crops were as follows:

Season	August rainfall (inches)	Percentage loss of protein during curing and harvesting			
		Oats	Peas	Beans	Mixture
1949	2·2	0·4	27·3	23·6	9·1
1950	8·3	31·6	40·8	39·9	43·7
1951	6·5	17·2	25·9	35·9	22·0

All the aforementioned losses were incurred during the handling of the crops under experimental conditions after the experimental sampling. The remainder of each crop was then immediately harvested in the normal way, being subjected therefore to the shedding and handling

losses that occur under ordinary farming conditions. The threshed grain was weighed and sampled in order to obtain the dry-matter and crude-protein yields; in 1950, because of the bad weather, it was

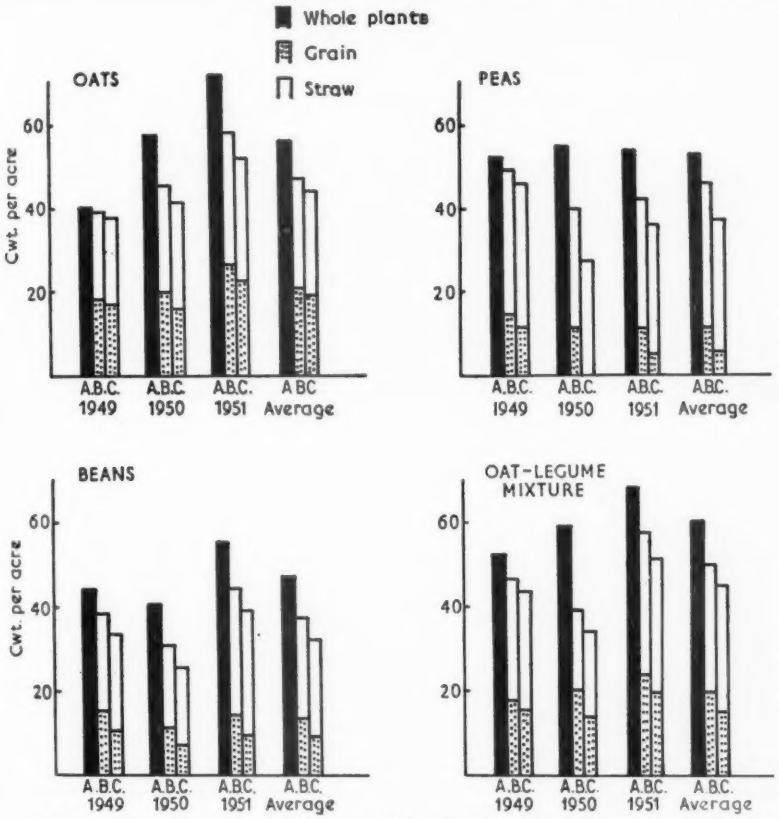

FIG. 1. The effect of curing and harvesting on the yields of dry matter from mature oats and legume crops.

Column A: From whole plants at time of cutting.
Column B: Grain and straw at time of threshing under experimental conditions.
Column C: Grain and straw at time of threshing under ordinary harvesting conditions.

impossible under ordinary farming conditions to harvest the peas in a fit state for threshing. The yields of the whole plants and of grain and straw harvested by both methods, in individual years, are shown in Figs. 1 and 2, the averages being given in Table 8.

In Figs. 1 and 2 and Table 8 it is evident that while the difference in yield of dry matter and crude protein between the time of cutting and threshing under experimental conditions was considerable, the loss was even more severe when the crops were cut by binder, stacked, and

threshed. The average yield, over 3 years, of the grain plus straw when the crops were harvested in this way in no case exceeded 80·1 per cent. in terms of dry matter, and 73·6 per cent. in terms of crude protein, of

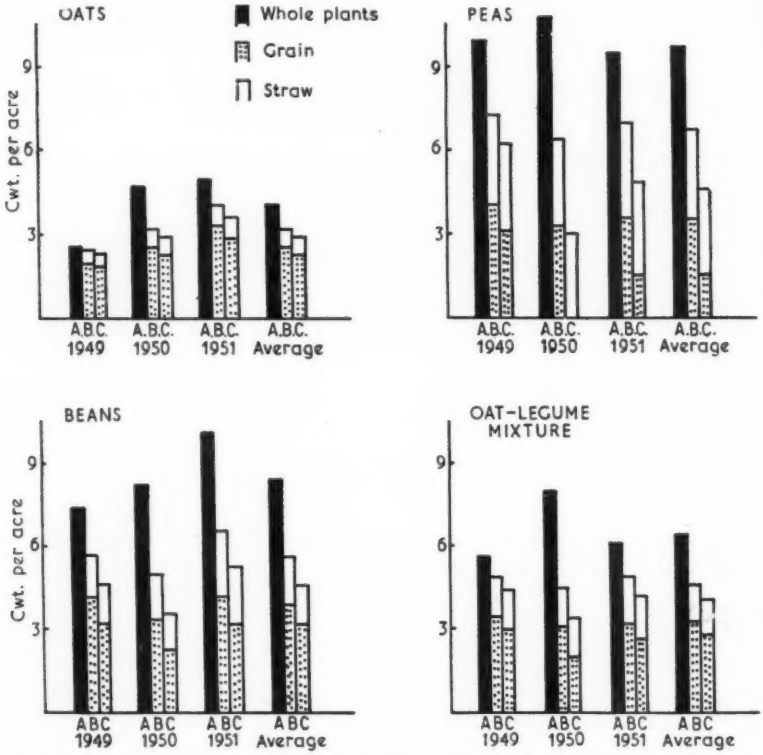

FIG. 2. The effect of curing and harvesting on the yields of crude protein from mature oats and legume crops.

Column A: From whole plants at time of cutting.
Column B: Grain and straw at time of threshing under experimental conditions.
Column C: Grain and straw at time of threshing under ordinary harvesting conditions.

the corresponding yields at the time of cutting. In the pea crop the crude-protein yield of the grain plus straw was only 47·8 per cent. of the crude-protein yield at the time of cutting.

4. *Comparison of Grain and Straw with Immature Green Material*

The losses that occur during harvesting raise the question whether a higher yield of animal nutrients would be obtained by cutting at an early stage of growth and drying or ensiling the crop.

The optimum stages of growth for cutting the green material for ensilage would be stages 3 and 4. Stage 2 would supply high-quality

green material, but the amount would be very small, the dry-matter yield at this stage being only 48 per cent. of that produced at stage 4. While the yield at stage 5 is somewhat higher than in the preceding stage, the crude-protein content is low for a medium-quality silage. Both

TABLE 8. *Yields of Mature Crops at Time of Cutting and after Harvesting by Experimental and Normal Methods*

(*Average of 3 years; cwt. per acre*)

	Yield at time of cutting (Stage 7)		*Yield of grain and straw*			
			By experimental procedure		*Cut by binder, stacked, and threshed*	
	D.M.	*C.P.*	*D.M.*	*C.P.*	*D.M.*	*C.P.*
Oats .	56·4	4·09	47·4	3·30	45·2	3·02
Peas .	53·2	10·02	45·3	6·83	38·0	4·79
Beans .	47·1	8·58	37·3	6·64	34·1	5·59
Mixture .	59·4	6·53	50·9	4·76	47·5	4·24
Expressed as percentage of yield at time of cutting						
Oats .	100	100	84·0	80·6	80·1	73·6
Peas .	100	100	85·1	68·1	71·4	47·8
Beans .	100	100	79·2	77·4	72·4	65·1
Mixture .	100	100	85·7	72·9	79·9	64·9

stages 3 and 4 have given satisfactory yields of medium-quality material, stage 4 giving a greater bulk with a slightly lower crude-protein content. The yields of dry matter and crude protein at these stages of growth are given in Table 9, for each crop, with the corresponding yields of grain and straw at the 7th stage of growth.

TABLE 9. *Yields of Dry Matter and Crude Protein as Green Material (Stages 3 and 4) and as Ripe Grain and Straw (Stage 7)*

(*Average of 3 years; cwt. per acre*)

	Stage 3		*Stage 4*		*Stage 7**					
					Grain		*Straw*		*Total*	
	D.M.	*C.P.*	*D.M.*	*C.P.*	*D.M.*	*C.P.*	*D.M.*	*C.P.*	*D.M.*	*C.P.*
Oats .	38·9	3·63	51·7	4·01	21·5	2·65	25·9	0·65	47·4	3·30
Peas .	36·0	7·84	51·0	10·59	13·0	3·66	32·3	3·17	45·3	6·83
Beans .	27·5	5·68	37·8	7·50	12·3	3·98	25·0	1·66	37·3	5·64
Mixture	41·2	5·42	56·1	6·82	20·1	3·40	30·8	1·36	50·9	4·76

* Yield under experimental conditions.

From the above it is evident that the crops cut at both the 3rd and 4th stages supplied much more dry matter and crude protein than did the grain, the peas and the oat-legume mixture at these stages giving more than double the dry matter and about double the crude protein derived

from the grain. Against this has to be placed the higher digestibility of the grain constituents, but when this was taken into account it was found that the green material from the oats at stage 4 supplied more starch equivalent than that provided by both grain and straw together, while the cereal-legume mixture at this stage supplied more digestible crude protein as well. This is shown by the following approximate estimates of starch equivalent (S.E.) and digestible crude protein (D.C.P.), in cwt. per acre, derived from stages 3 and 4 and from the grain and straw in stage 7:

	Stage 3		*Stage 4*		*Stage 7**		*Stage 7†*	
					Grain+Straw		*Grain+Straw*	
	S.E.	*D.C.P.*	*S.E.*	*D.C.P.*	*S.E.*	*D.C.P.*	*S.E.*	*D.C.P.*
Oats . .	17·5	2·36	23·3	2·40	20·5	2·29	19·0	2·07
Oat-legume .	17·7	3·14	25·5	3·96	21·2	3·24	18·7	2·82

* Yield under experimental conditions.
† Yield under normal harvesting conditions.

It is reasonable to infer that, even after the losses entailed in making silage from the oat-legume mixture, the product from stage 4 would still provide as much starch equivalent and digestible protein as that to be derived from the grain and straw at maturity under ordinary farm conditions.

Discussion

In this experiment, taking the average of the three seasons, the dry-matter yield of the oats reached a maximum 2 or 3 weeks before the full-ripe stage, and, as the crude-protein percentage in the dry matter remained fairly constant in the last stages of sampling, the crude-protein yield of the whole plants showed little variation over the ripening period. It would follow, therefore, as shown by Berry [4], Watkin [5], and Smith and Robb [6], that the increase in the yield of crude protein in the oat grain over the final stages of ripening was due entirely to translocation from the other parts of the plants.

The peas produced a great bulk of green material and, although the percentage of dry matter was not high, a considerable yield of dry matter was obtained. The dry-matter yield rose until the pods began to fill, but showed very little increase during the last month of maturation, nor was there any increase in the yield of crude protein over this period. Unlike the oats and peas, the bean crop showed a definite increase in the dry-matter yield until the ripe stage, and similarly the crude-protein yield increased steadily throughout the whole of the growing period.

In the oat-legume mixture, while the dry-matter yield increased until the penultimate sampling stage in each season, there appeared to be a slight decrease in the crude-protein yield over the last week of ripening. The probable cause was a combination of leaf fall and shedding losses as the crop reached maturity, and the more mature the crop the more liable would it be to such losses.

There was considerable variation in the proportion of each constituent in the mixture from one season to another, but the proportions remained fairly uniform throughout the sampling period in each season. As was suggested by Bacher [7] the factors controlling the balance of cereal to legume in the mixture are complex, and instead of showing complementary growth, the cereal and the legume constituents appear to grow in competition with one another. In any season, therefore, climatic and soil factors which specifically encouraged the growth of the oats upset the balance in favour of this constituent, and the growth and vigour of the legumes were reduced by competition and smothering, in the early stages of growth, by the more strongly growing oat plants.

In each season the beans contributed little to the yield of dry matter or crude protein, nor did they appear to serve the purpose for which they were originally included—to support the weaker-strawed peas and to help prevent lodging of the crop. Under the conditions of the experiment, therefore, there is little point in including beans in a cereal-legume mixture for silage making or for grain production if all the constituents are to be sown at the same time. This, of course, does not apply to a winter-sown mixture of oats and beans, nor would it apply if the spring beans were sown some time earlier than the oats and peas. In districts of high rainfall, however, where excess of soil moisture is the limiting factor to early spring cultivation, early sowing of the beans would not be practicable because the spring cereals and cereal-legume mixtures are all normally sown as soon as soil conditions are suitable.

During the period under review, while the oats grown alone gave a slightly higher yield of dry matter than the peas, the highest average yield was provided by the oat-legume mixture. In each year of the experiment the peas yielded the greatest, and the oats the least, amount of crude protein. Early in the growing season, however, the peas lodged very badly and on a field scale difficulty would have been encountered in cutting this crop.

The above comparisons refer to the yields obtained at the time of cutting, before harvesting losses were entailed. When the crops were harvested at full maturity the highest average yield of dry matter was derived from the oat grain, while a greater yield of crude protein was obtained from the mixture grain than from the oats. The pure legumes, particularly the peas, showed marked seasonal variations in their yield and were thus unreliable for seed production. In every case the yield of dry matter and crude protein obtained by experimental threshing was considerably less than the yield of these constituents derived from the whole crop at the time of cutting. The losses that occurred depended mainly on the type of crop and the weather conditions during harvest, being most severe in the legumes and in the seasons with inclement weather at harvest. Still greater losses took place when the crops were cut by binder, stacked, and threshed under ordinary farming conditions. Because of these losses, at the stages of growth (stages 3 and 4) when the crops were suitable for the production of medium-quality silage, the yields of dry matter and crude protein in the green material of the four crops were greater than the corresponding dry-matter and

crude-protein yields of the grain and straw. An approximate estimate showed that the immature material also yielded more starch equivalent and digestible crude protein than that obtained from the grain and straw.

Summary

An experiment carried out over a period of 3 years at a centre near the coast of Mid-Wales compared the productivity, at seven stages of growth, of oats and legumes grown singly and in a mixture.

The oat-legume mixture gave a higher average yield of dry matter than any of the crops grown singly, while the peas yielded the greatest amount of crude protein. Other relationships between the single crops and those grown in the mixture varied from season to season.

During the curing and harvesting of the crops for grain production, shedding and handling losses caused serious reductions in yields of dry matter and protein.

Because of these losses the animal nutrients available in the grain and straw were less than those derived from the green material when cut at a stage of growth suitable for ensilage.

Acknowledgements

The writers desire to acknowledge the valuable help received from the late Emeritus Professor T. W. Fagan, and to thank Professor W. Ellison for his helpful interest and the Ministry of Agriculture for a grant that made the work possible.

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(*Received 30 November 1954*)

THE OVERWINTERING OF BEEF STORES

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WITH the increased demand for beef produced from home sources, at a price acceptable to the consumer and allowing an adequate margin of profit to the producer, there is need for a comprehensive examination of the methods of breeding, feeding, and general management for producing this commodity. In grazing-management experiments in progress at the Grassland Research Institute, some emphasis has been placed on the overwintering of steers during their second winter at an age of 18–21 months, these cattle being subsequently used for fattening on experimental pastures in the following summer. In the past, steers were purchased as yearlings in the spring of the year, and management was on the traditional Welsh-border system of the Hereford suckler herd, the calves being born in spring and wintered on the home farm for their first winter. Initial feeding was on this account at a high plane of nutrition and the cattle as yearlings were well grown and of good constitution. At Hurley the steers have been bought in as colour-marked calves, using a Hereford bull, and reared on the multiple-suckling principle. Thus in the earlier phases of the investigations fairly mature cattle were used in the experiments, but as time proceeded, younger cattle have been brought in, so that at the present time the stock used are more in keeping with market demands than those turned out under war-time control conditions.

The phase of grassland-management investigation with which the present inquiry is concerned is that of the wintering of the cattle between the ages of 18 months and 2 years. The main purpose of the investigation was to study methods of grass production and utilization in the field during the winter months, followed by the summer production from such winter-pastured areas. The earlier findings of the experiments have been discussed by Hughes [1]; details of the performance of cattle overwintered at grass out-of-doors are now available for the winters of 1951–2, 1952–3, and 1953–4. To widen the scope of the investigations similar groups of cattle were also kept under other methods of overwintering. Further, the summer performance of the animals kept under each overwintering treatment was recorded for 1952, 1953, and 1954.

Pawson *et al.*, in a number of papers [2], have discussed the wintering of store cattle at Cockle Park from 1947–8 to 1952–3. As part of their investigations they included two groups of bullocks, varying in number between nine and ten in each group from year to year, and of the age of suckler calves weaned in the October immediately previous to the experimental period. These cattle were not of the age or weight of those with which the present paper is concerned; however, the results are of interest in that two methods of overwintering were adopted by these workers, namely, inside wintering and outside wintering, the composition

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

of the rations fed in each instance being similar except that roots were omitted in the case of the outwintered cattle. In a summary of the live-weight performance the following table was given to show the changes that took place in the winter and summer periods from 1947 to 1953:

Average Increase in Live-weight of Bullocks during Winter and Summer Feeding Trials, 1947–53 (lb.) Cockle Park. Pawson et al. [2]

	1947–8	*1948–9*	*1949–50*	*1950–1*	*1951–2*	*1952–3*
Out-wintered	291 (235)	299 (186)	200 (148)	241 (179)	336 (194)	259 (165)
Inwintered	283 (142)	346 (145)	317 (176)	286 (104)	339 (169)	291 (137)

(The figures in parentheses represent the mean gains for the summer period of 14 weeks.)

These authors noted that the inwintered stock gained more weight during the experimental winter period and were heavier than the outwintered stock. In spite of this the latter were generally valued higher per head than the former in the spring, and when turned out to grass those inwintered did not gain weight as rapidly as those outwintered. In total gain of weight over the winter and summer periods the inwintered bullocks were, however, superior to those wintered outside.

Findlay [3], dealing with various methods of feeding cattle wintered inside and outside over a number of seasons under Aberdeenshire conditions, showed that cattle fed outside in the field, and with shelter and dry lying available, put on better live-weight gains during the winter than similar cattle housed inside. The outwintered cattle consumed more turnips than those fed inside, and the live-weight gain obtained outside increased at the higher rate of turnip feeding. When turned out to grass in the spring, the inwintered cattle lost considerable weight in the first week, but after this initial set-back they gave higher summer live-weight gains than those wintered outside. Over the whole period under observation the field-wintered cattle gave higher gains than those wintered inside, were generally ready to sell first, and gave a greater dead-weight percentage, although the differences between the two groups were small. Findlay in his summary concluded that 'Cattle whether wintered inside or outside did not increase steadily but advanced in weight by "fits and starts". Thus, if an animal did poorly for a period it usually did well during the next period. On the other hand, when it did particularly well during one period it very often did poorly during the next. . . .' He also stated that the quality of the animals had a considerable effect on the result, for there was a wide variation in the live-weight increases shown by animals from different sources kept under the same conditions.

Steensberg [4] summarized the results, obtained over 12½ years from 1928, of experiments dealing with the feeding levels of heifers from birth to first calving at 2½ years old. The animals concerned were fed at three levels, light, normal, and heavy, during the indoor winter-feeding periods, while for the 6 summer months heifers over 10 months had only grass and all fed on the same pasture. Steensberg noted that the lightly fed

animals made the largest gain in weight in summer, as is shown in the following table which gives the average results for three breeds:

Group	Total kg.	Gain in weight			
		Winter		Summer	
		kg.	% of total	kg.	% of total
Lightly fed	339	196	58	143	42
Normally fed	368	247	67	121	33
Heavily fed	394	280	71	113	29

During the course of the same experiments, Steensberg showed that with heifers 12–18 months of age, which had been differentially fed during the winter at the three levels mentioned and which were indoor-fed during the summer on unlimited fresh grass, clover, or lucerne, the lightly fed animals gained about 200 gm. more per head daily than the heavily fed ones. He suggested that it would not pay the practical farmer to feed 12–15 months-old heifers heavily in winter, if he had good grazing available for summer feeding. A somewhat lighter winter feeding would give the most economical utilization of the summer grazing.

Experimental

In the series of experiments with which the present paper deals, the main purpose was not a comparison of winter-feeding methods but rather an inquiry into the possibilities of utilizing later-summer- and autumn-grown grass, preserved as grown in the field, for outwintering stores that would come for summer fattening on grass the following season. The cattle overwintered in this manner were given the harshest of treatment in so far as shelter and dry lying were concerned—these being to all intents and purposes non-existent. It was considered that if reasonable results could thus be obtained the conditions could very easily be improved and better results obtained in consequence. It was with a view to providing some comparison of treatments that other methods of overwintering were studied at the same time.

The earlier experiments, of 1951–2 and 1952–3, were conducted at Drayton, Stratford-on-Avon, where the soil type is heavy Lower Lias clay. In 1953–4 two experiments were carried out; one of these was again at Drayton and the other was at Hurley, where the soil type is clay-with-flints overlying chalk. Thus, in all, four experiments were conducted in the three winters between the autumn of 1951 and the summer of 1954.

Table 1 gives the average maximum and minimum air temperatures, the total number of ground frosts, and the rainfall in inches recorded at Drayton during the 5 months November to March in 1951–2, 1952–3, and 1953–4.

In 1951–2 these 5 months were fairly normal with regard to weather conditions, only the November rainfall being exceptional. The same period in 1952–3 will be remembered for the very early onset of cold conditions, in the autumn, which persisted throughout the period. Snow

fell in late November, in early December, and again in January and early February. 1953–4 was exceptional for the extremely mild conditions that persisted up to Christmas. Some snow fell in January, and spring growth was retarded mainly through cold winds and lack of sunshine, May 1954 being extremely low in this respect and giving 107 hours as compared with 189 hours for the 10-year period 1941–50.

Winter 1951–2.—In this first experiment on the different methods of overwintering beef stores, the main objective was to consider the possibility of pasturing cattle on winter grass especially prepared on grass-lucerne drills in experiment E. 158. The cattle chosen for this purpose were selected with a view to their being of an age capable of

TABLE 1. *Air Temperature, Number of Ground Frosts, and Rainfall; Drayton, Stratford-on-Avon, November to March, 1951–2, 1952–3, and 1953–4*

	Maximum air temperature, °F			*Minimum air temperature, °F*			*Number of ground frosts recorded, i.e. < 30·4 °F*			*Rainfall in inches*		
	1951–2	*1952–3*	*1953–4*	*1951–2*	*1952–3*	*1953–4*	*1951–2*	*1952–3*	*1953–4*	*1951–2*	*1952–3*	*1953–4*
Nov.	52·5	41·8	52·3	40·2	31·5	40·8	4	22	5	5·52	2·36	1·29
Dec.	49·8	43·5	47·5	34·5	30·8	38·8	9	18	5	1·87	2·14	0·76
Jan.	42·0	42·3	40·8	31·2	31·8	28·8	24	23	24	1·31	0·78	1·07
Feb.	45·0	45·0	44·5	31·8	31·8	31·5	19	21	15	0·47	1·32	2·05
Mar.	50·8	52·0	50·5	37·5	32·3	37·5	11	17	2	2·21	0·87	1·83

withstanding adverse conditions, and of a type that would readily fatten in the following summer and make the grade before the then-prevailing Ministry of Food prices dropped during midsummer. These cattle, therefore, averaged 2 years of age when the experimental period commenced in the late autumn, and had an average live weight of around 1,250 lb.

Three winter-feeding treatments were imposed, namely inwintering, outwintering and hand feeding, and outwintering on winter grass. The cattle were divided into three groups, A, B, and C respectively, for this purpose. Live weights were recorded from 11 November 1951 to 8 July 1952, when the experiment was completed. All three groups consisted of five cattle during the 1952 summer, but during the winter Group A formed part of a bunch of sixteen cattle that was wintered in a covered but open-sided Dutch barn, with straw bales making up a yard. Group B, which was outwintered on several accommodation pastures that were available, consisted of part of a bunch of eight cattle wintered in this manner. Group C consisted of six beasts during the winter, these being reduced to five during the summer.

Group A cattle were taken into the yards on 14 November, and Group B were hand fed from this time. Group C commenced winter grazing, using an electric fence to ration the feed, on 10 December, and this grazing was completed on 12 March. From this time to 17 April the cattle

were strip-grazed on Italian ryegrass and were given part of their ration as hay in addition. On 17 April all three groups were brought together and put on to spring pasture, where they remained until 8 July when most of them were graded. Both groups of outwintering cattle, B and C, had no shelter of any kind and lay out in this manner the whole time. The feeding of Groups A and B in the winter was based on grass silage with

TABLE 2. *Live-weight Performance, 1951–2*

(*Average live weight in pounds*)

Weighing date	*Group A* (5)[1] *inwintered*	*Group B* (5) *outwintered and hand fed*	*Group C* (5) *outwintered on winter grass*
14 November	1,207	1,334	1,252
19 December	1,238	N.A.[2]	1,250
14 January	1,249	N.A.[2]	1,246
7 February	1,297	1,271	1,252
17 March	1,334	1,296	1,225
17 April	1,363	1,305	1,290
Total winter increase or loss	+156	−29	+38
Winter increase in lb. per day	1·00	..	0·24
15 May	1,376	1,378	1,359
12 June	1,439	1,475	1,446
8 July	1,487	1,530	1,512
Total summer increase	124	225	222
Summer increase in lb. per day	1·53	2·78	2·74
Total increase winter and summer	280	196	260
Increase in lb. per day	1·18	0·83	1·10

[1] In this and later Tables the number of animals in a Group is shown in parentheses.
[2] N.A. = not available.

oat straw or hay. Silage of an average dry-matter content of 25 per cent., with crude protein 14·6 per cent. and pH 4·55–5·05, was fed up to 70 lb., with sufficient straw or hay to make up a dry-matter intake of 25 lb. per head daily.

The performance, as reflected in live-weight change, of the cattle treated in this manner during the winter, together with their subsequent summer performance, is given in Table 2.

This shows that the inwintered cattle of Group A gained an average of 156 lb. per head from November to April, at a daily rate of gain of 1 lb. per head. Group B lost an average of 29 lb. per head, while Group C, which lost weight in the February–March period, gained again when Italian ryegrass became available for grazing in March, and the cattle showed an average increase for the period of 38 lb. per head. In the summer-grazing period the greater winter increase of Group A was offset by a smaller summer gain as compared with Groups B and C. Although

it does not appear in Table 2, Group A lost weight in the early period of turning out to grass in the spring, and even after the cattle had been conditioned to the new habit of feeding for a month, gain in weight was only slight compared with Groups B and C which suffered no setback at this time. The average summer gains of Groups A, B, and C were 124, 225, and 222 lb. per head, with daily gains of 1·53, 2·78, and 2·74 lb. respectively. Over the whole of the experimental period the average gains per head were 280, 196, and 260 lb. for the three Groups A, B, and C respectively, giving a daily increase of 1·18, 0·83, and 1·10 lb. per head.

Winter 1952–3.—The steers selected for the experiments conducted in the winter of 1952–3 were younger than those used during the previous winter, their ages being between 18 and 21 months in the autumn of 1952. The three treatments, inwintering, outwintering and hand feeding, and outwintering on winter grass, were again followed with the cattle of Groups A, B, and C respectively. The cattle of Group A were on average lighter than those of Groups B and C, those inwintered being purposely selected as being the smaller animals. Group A consisted of three beasts whose weights were recorded during the whole of the experimental period, and these formed part of a bunch of twelve cattle which was housed in a yard situated in a covered-in Dutch barn. Group B formed part of another bunch of twelve cattle which was outwintered on the same accommodation pasture field throughout the winter. Group C consisted of six cattle during the winter period, these being reduced to five in the summer as one beast persistently broke through the electric fence. Group A was brought in on 17 November and remained in the yard until 15 April following, when together with Group B it was put in to join Group C in the grass-lucerne drills of the E. 158 experimental area.

The feeding of Groups A and B during the winter was again based on grass silage with oat straw or hay, together with what grazing was available on the pasture for Group B. No dry lying or shelter was afforded either Groups B or C, and the form of overwintering was purposely made as rigorous as possible. The quantity of grass silage fed was 70 lb. per head daily at an average dry-matter content of 20 per cent., and sufficient oat straw or hay was fed to make up a dry-matter intake of around 22 lb. daily. The crude-protein content of the dry matter of the grass silage averaged 14·5 per cent., with some variation according to the pit being fed and the position of the silage within the pit. The pH varied from 4·30 to 5·16. From 17 November to 18 February Group C was grazed, with the electric fence, on grass-lucerne drills in experiment E. 158, without supplementary hand feeding. From 18 February, when winter pasturing was completed, to 15 April, when spring pasture became available, the cattle received half their ration as hay and half as Italian ryegrass, again strip-grazed with the electric fence.

During the spring and summer, from 15 April to 23 August, Groups A, B, and C were pastured under experimental conditions on the grass-lucerne drills of E. 158. Grazing was controlled with the electric fence and no supplementary feed was given during this period.

Table 3 gives the average live-weight performance of the three groups

of cattle from 28 October 1952 to 23 August 1953, when the experiment was completed. By the end of the winter-feeding period all groups showed gains, Group A being highest with 79 lb. per head, followed by Group B with 22 lb., and Group C with only 10 lb. During the course of the winter, however, both Groups B and C lost weight in February–March. This loss was made up again by Group C when Italian ryegrass became available for grazing from 18 March, while Group B made up the loss as normal pasture growth took place in the early spring.

TABLE 3. *Live-weight Performance, 1952–3*

(*Average live weight in pounds*)

Weighing date	*Group A* (3) *inwintered*	*Group B* (3) *outwintered and hand fed*	*Group C* (5) *outwintered on winter grass*
28 October	987	1,099	1,128
17 November	1,006	1,109	1,127
9 December	1,003	1,095	1,124
6 January	1,003	1,095	1,111
10 February	1,003	1,067	1,038
17 March	1,043	1,078	1,067
15 April	1,066	1,121	1,138
Total winter increase	+79	+22	+10
Winter increase in lb. per day	0·47	0·13	0·06
15 May	1,102	1,183	1,201
12 June	1,186	1,281	1,303
18 July	1,206	1,270	1,317
23 August	1,269	1,329	1,374
Total summer increase	203	208	236
Summer increase in lb. per day	1·57	1·61	1·83
Total increase winter and summer	282	230	246
Increase in lb. per day	0·94	0·77	0·82

In the summer period of 1953, when all the cattle from the three groups were pastured together on the grass-lucerne drills of E. 158, there was little difference in the live-weight gains between Groups A and B, while Group C was on average a little higher, the gains being 1·83, 1·61, and 1·57 lb. per head daily for Groups C, B, and A respectively. Taking into account the whole of the experimental period, Group A gave the highest gain of 282 lb. (0·94 lb. per head per day), followed by Group C with 246 lb. (0·82 lb. per head daily), and Group B with 230 lb. (0·77 lb. daily gain).

Winter 1953–4.—As explained previously, two separate experiments on the wintering of store cattle were conducted in the 1953–4 winter. The first of these was located at Drayton, Stratford-on-Avon, as were the experiments already described for 1951–2 and 1952–3, while the second took place at Hurley.

In the Drayton experiment the cattle were again in three groups, A, B, and C, inwintered, outwintered and hand fed, and outwintered on winter grass respectively, as in previous years. The three groups were again not strictly comparable as the younger and lighter beasts were those selected for inwintering, while those outwintered in Groups B and C were a little older and heavier. Their ages ranged from 18 to 21 months in the autumn of 1953. The four beasts, followed throughout the experimental period as Group A, were part of a bunch of twenty-four similar cattle wintered in an open yard; the four in Group B were among nine beasts; and Group C was made up of eight cattle for both the winter

TABLE 4. *Live-weight Performance, Drayton, 1953–4*

(*Average live weight in pounds*)

Weighing date	*Group A* (*4*) *inwintered*	*Group B* (*4*) *outwintered and hand fed*	*Group C* (*8*) *outwintered on winter grass*
27 October	931	1,004	1,093
8 December	881	1,030	1,100
6 January	919	..	..
22 January	..	996	1,088
11 February	908	..	..
24 March	968	1,027	1,019
26 April	1,024	1,027	1,051
Total winter increase or loss	+93	+23	−42
Winter increase in lb. per day	0·51	0·13	..
4 May	975	1,046	1,072
4 June	1,017	1,123	1,142
12 July	1,066	1,171	1,192
13 August	1,103	1,200	1,240
17 September	1,164	1,262	1,296
Total summer increase	140	235	245
Summer increase in lb. per day	0·98	1·64	1·72
Total increase winter and summer	233	258	203
Increase in lb. per day	0·72	0·79	0·63

and summer periods. Group A was brought in on 8 December and remained in the yards until 26 April, when it was turned out to accommodation pasture. On 4 May Group A and Group B, comprising eight cattle in all, joined Group C in the experimental area of E. 158 where Group C had been overwintered.

The winter feeding of Groups A and B consisted of grass silage and oat straw or hay. The quantity of silage fed was 60 lb. per head daily, with sufficient oat straw or hay to give a dry-matter intake of 22 lb. The crude-protein content of the dry matter of the silage varied from 13·9 to 15·1 per cent., and the pH from 4·88 to 5·65, the variation being due to different pits and to the location of the silage within the pit.

During the summer, until the end of the experimental period on 17

September 1954, the sixteen cattle were pastured on the grass-lucerne drills of experiment E. 158. Grazing was rationed with the electric fence throughout this period, and no supplementary feed was given.

Table 4 gives the average live-weight changes for the three Groups A, B, and C, from 27 October 1953 to 17 September 1954. Group A showed an increase of 93 lb. per head over the winter and Group B, 23 lb. Group C lost somewhat severely during February and March, but when Italian ryegrass became available for grazing on 13 April 1954, a gain in weight became apparent, the final loss being 42 lb. It should be noted, however, that none of these cattle received supplementary feed as hay or silage, as did Group C in the previous two winters. It should also be borne in mind that the cattle were being used to assess the value of

TABLE 5. *Winter Feeding of Store Cattle, Hurley, 1953–4*

Treatment	*Period*	*Feed in lb. per head per day*		
		Hay	*Silage*	*Oats*
A. Inwintered	16 November–5 March	7	76	..
B. Outwintered and hand-fed	(i) 16 November–5 April	7	56	..
	(ii) 16 November–5 April	7	80	2
C. Outwintered on winter grass and permanent pasture	(i) 16 November–8 February	..	..	..
	9 February–8 March	7	28	..
	9 March–5 April	7	56	..
	(ii) 16 November–8 March	7	28	2
	9 March–5 April	7	80	2

different species and strains of grasses for winter pasture, and in some instances the bulk of feed available proved insufficient. With the knowledge now available of the suitability of certain species for winter production as well as reasonable quality, it is considered that the loss in weight experienced by Group C could be avoided.

It will be noted from Table 4 that the weights of the cattle are given on 4 May, shortly after Group A had been turned out, and even though this group was in an open yard over winter, loss in weight was recorded in the early period of turning out to pasture. This did not occur with Groups B and C, where slight gains were recorded when the animals were turned into the summer grazings. This loss of weight in the early period of turning out is a common feature of inwintered cattle, but it was not recorded in 1952 and 1953 as the corresponding weights in Tables 2 and 3 were measured approximately a month after turning out. Generally after three or four weeks of pasturing the inwintered cattle begin to increase in weight as they become adapted to the change of environment and feed.

The 1954 summer gains were considerably in favour of Groups B and C, with the latter slightly ahead of the former. Daily gains per head at this time were 0·98, 1·64, and 1·72 lb. for Groups A, B, and C respectively. The total gains over the whole experimental period favoured Group B, at 258 lb. per head, with Group A next at 233 lb. and Group C

the poorest at 203 lb., to give 0·79, 0·72, and 0·63 lb. gain per head per day respectively.

From Table 7, showing the final dates of slaughter together with grade and carcass weight, it will be noted that of Group A, one beast was marketed in October, one in November, and two in December.

TABLE 6. *Live-weight Performance, Hurley, 1953–4*
(*Average live weight in pounds*)

Weighing date	*Group A* (7) *inwintered*	*Group B* (7) *outwintered and hand fed* (i)	(ii)	*Group C* (7) *outwintered on winter grass* (*i*)	(*ii*)
16 November	982	984	1,007	994	1,001
14 December	1,014	1,028	1,051	990	1,023
11 January	1,009	1,038	1,088	958	1,025
9 February	1,044	1,063	1,109	907	1,058
8 March	1,018	1,020	1,086	957	1,033
5 April	1,026	1,012	1,112	933	1,062
Total winter increase or loss	+44	+28	+105	−61	+61
Winter increase in lb. per day	0·31	0·20	0·75	..	0·45
29 April	1,047	1,098	1,147	992	1,125
31 May	1,134	1,172	1,228	1,086	1,184
28 June	1,213	1,241	1,285	1,176	1,252
Total summer increase	187	229	173	243	190
Summer increase in lb. per day	2·23	2·73	2·06	2·89	2·26
Total increase winter and summer	231	257	278	182	251
Increase in lb. per day	1·03	1·15	1·24	0·81	1·12

Group B gave one beast to be marketed each month from September to December inclusive, while Group C gave four in condition for September marketing, one in October, two in November, and one in December. This was to some extent a reflection of age as well as condition, but it serves to indicate that the loss in weight experienced during the winter with Group C did not retard the time at which slaughtering condition was reached.

In the experiment at Hurley the cattle were again managed in three main groups, A, B, and C, inwintered, outwintered and hand fed, and outwintered on winter grass respectively. Groups B and C were each subdivided into two treatments, giving Groups B (i) and B (ii), and C (i) and C (ii). Thirty-five cattle, cross-bred steers rising 2 years old, were available for the experiment and each group or sub-group consisted of seven beasts. The quantities supplied in winter feeding are given in Table 5.

Group A was inwintered from 16 November to 5 April, and fed on grass silage and hay. Group B was outwintered on a sheltered permanent pasture. Group B (ii) received 24 lb. of silage and 2 lb. of oats more per

TABLE 7. *Dates of Slaughter, Carcass Grading, and Weight, 1954*

Drayton				*Hurley*			
Group	*Date of slaughter*	*Carcass grade*[1]	*Carcass wgt. in lb.*	*Group*	*Date of slaughter*	*Carcass grade*	*Carcass wgt. in lb.*
A	13 Oct.	A	711	A	5 July	A	712
	10 Nov.	A	652		7 Aug.	A	690
	11 Dec.	A	696		29 Aug.	A	861
	16 Dec.	A	706		29 Aug.	A	745
					29 Aug.	A	747
					29 Aug	A	657
					17 Sept.	A	766
B	29 Sept.	A	694	B (i)	5 July	B	688
	13 Oct.	A	701		5 July	A	798
	10 Nov.	A	651		5 July	A	720
	11 Dec.	A	754		5 July	A	708
					17 Sept.	A	864
					17 Sept.	A	668
					17 Sept.	A	774
				B (ii)	5 July	A	774
					5 July	A	768
					5 July	A	712
					5 July	A	700
					5 July	A	760
					7 Aug.	A	768
					29 Aug.	A	798
C	29 Sept.	A	852	C (i)	7 Aug.	A	688
	29 Sept.	A	744		17 Sept.	A	755
	29 Sept.	A	740		17 Sept.	A	788
	29 Sept.	A	1,022		17 Sept.	A	807
	13 Oct.	A	674		17 Sept.	A	659
	10 Nov.	A	662		17 Sept.	A	710
	10 Nov.	A	667		17 Sept.	A	740
	11 Dec.	A	728	C (ii)	5 July	A	791
					5 July	A	816
					7 Aug.	A	743
					7 Aug.	A	781
					7 Aug.	A	663
					29 Aug.	A	743
					17 Sept.	A	755

[1] Carcass grades A and B represent a minimum killing-out percentage of 54, with conformation as specified by the British Ministry of Food under the Fatstock Guarantee Scheme, 1954.

head than Group B (i). Group C was grazed on a field exposed to the north and east from 11 November to 8 March, when the group joined Group B cattle on permanent pasture. Group C (ii) was supplemented with hay, silage, and oats during this time, while Group C (i) was not hand-fed until 8 February, when the cattle received supplementary hay

and silage but no oats. From 8 March to 5 April Group C (ii) received 24 lb. of silage and 2 lb. of oats more than Group C (i). Weather conditions were severe in January and February 1954, particularly for the Group C cattle which were exposed to very cold north-east winds for long periods. Ground frost occurred on 15 days in January and 14 days in February, while there was snow or rain on 6 days in January and on 13 in February.

Dry-matter content of the grass silage fed varied from 16 to 24 per cent.; the crude protein of the dry matter averaged 8·4 per cent., and the pH 5·3. The low quality of the silage was due to its being made from over-mature herbage in mid-June.

Table 6 shows that the average live weights of the seven steers in the five groups were balanced as nearly as possible at the start of the experimental period. During the course of the winter, Group C (i), feeding on pasture until 8 February, received a severe check; this was partly accounted for by the quality and amount of herbage available for grazing in January. All the remaining groups gained in weight during the winter, the cattle in Group B (ii), at the higher plane of supplementary feeding outside, doing best. The cattle on this treatment received *ad lib.* feeding while on pasture, and were in a semi-fat condition by February.

From 5 April onwards all groups were given uniform treatment and were grazed on the same pastures. The results show that during the spring and summer, up to 28 June, the cattle that received the severe check during the winter, Group C (i), gained the most live weight. This group gained an average of 56 lb. per head more during the summer than the inwintered Group A, and 70 lb. per head more than Group B (ii). Over the whole of the experimental period Group A gained a total of 231 lb. per head, Group B (i) 257 lb., Group B (ii) 278 lb., Group C (i) 182 lb., and Group C (ii) 251 lb. The daily gains per head were respectively 1·03, 1·15, 1·24, 0·81, and 1·12 lb. All groups that were adequately fed outside showed higher gains than Group A which was inwintered. The only exception was Group C (i), which was fed on winter grass inadequate as regards bulk and quality.

Table 7, giving slaughtering details, shows that Group B (ii) was the first and Group C (i) the last to reach slaughter condition. The adverse management of the latter group, however, seemed to have little effect on carcass quality.

Summary and Discussion

Experiments on three main methods of overwintering beef stores were carried out during the winters of 1951–2, 1952–3, and 1953–4. The methods were (*a*) inwintering, (*b*) outwintering and hand feeding, and (*c*) outwintering on winter grass. The live weights of the cattle were recorded both during the winter and during the summer period following. Hereford or Hereford-cross steers, mainly 18 months to 2 years of age, were used in the experiments, such stock being hardy in type and able to convert grass to beef in an efficient manner.

In the three experiments carried out at Drayton, the inwintered cattle gave higher live-weight gains during the winter than did those wintered

in the field. The latter were generally kept at maintenance levels only, which resulted in little gain in weight or even in loss of weight. The summer gains, however, were always in favour of the outwintered stock, whether they had been hand-fed or grazed on winter pasture. The combined gains for both winter and summer differed from year to year, the inwintered cattle doing best in two years and the outwintered and hand-fed group being the poorest in these two years, the winter-pasture group being intermediate in performance. In the third year of experiment the outwintered and hand-fed group did best, followed by the inwintered group, with the winter-pasture group the poorest. In no instance, however, was general performance poor and the final results at slaughter were satisfactory with all groups.

In the Hurley experiment, the outwintered group which had been liberally fed was the best in total live-weight gain, closely followed by that outwintered and hand-fed at a lower level, and that on winter pasture with supplementary feeding from the beginning. The poorest cattle were those outwintered on winter pasture alone.

These results, and those of other workers mentioned, indicate that provided enough feed can be supplied to outwintered store stock to supply maintenance and secure a small gain in weight, it is these cattle that will show the best returns in terms of final gain over the summer fattening period. It is important that the cost of feed and labour should be reduced to a minimum to cheapen the cost of beef production. The adoption of a system of overwintering on winter pasture with the minimum of feed supplementation offers possibilities in this respect. Evidence is accumulating that specific techniques of pasture and stock management make it possible to produce feed sufficient in quality and quantity to keep cattle at grass in the winter without loss of weight. The subsequent performance of the cattle has here been shown to be satisfactory, as regards both live-weight gain and the production of a good meat carcass. The carcass is of similar quality to that obtained from inwintered cattle.

Acknowledgement.—The interest and encouragement of Dr. William Davies throughout the course of the experiments is acknowledged.

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(*Received 18 April 1955*)

A CLASSIFICATION OF CULTIVATED GROUNDNUTS

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A COLLECTION of more than two hundred varieties and selections of the cultivated groundnut, *Arachis hypogaea*, is maintained under rain-grown conditions at Tozi Research Farm. This is the Central Rainlands research station of the Research Division of the Sudan Ministry of Agriculture, located near Wad en Nail, Singa district, in the Blue Nile area of the Sudan (approx. 12° 30′ N. lat., 34° 0′ E. long.). The collection contains material assembled in 1947–51, from many parts of the world, by the scientific department of the Overseas Food Corporation in Tanganyika, together with accessions from the Sudan and from other territories in Africa. The method of classification presented in the present paper is based on two years' observation in Tanganyika followed by closer study for three seasons of the whole collection at Tozi.

It is not claimed that the observations will all be valid under conditions very different from those of Tanganyika or the central Sudan, since environmental effects may influence the expression of characters. However, characters which appear, from the literature or from observation, to be affected in this way have not been used for diagnosis. It is hoped that the present paper may lead to a better understanding of the nature of these environmental effects.

In Tanganyika the collection was grown on sandy or loamy clay soils; in the Sudan it is grown on a heavy alluvial clay soil, whose surface cracks finely on drying. No essential difference in the expression of important characters, including yield, has been noted between the two regions.

The nature of groundnut varieties.—Under semi-arid African conditions groundnut varieties appear to be reasonably stable. The instability discussed by Gregory, Smith, and Yarbrough [1] has been observed only where the initial stocks were demonstrably mixed, and has always been eliminated within a very few seasons by vigorous roguing or by filtering through progeny rows. Chance outcrossing has been observed but rarely, and segregation commences at once. No real evidence of genetic instability has been found in this work or in farm practice over several years.

No groundnut variety known to the author can be reliably rogued by inspection of the aerial parts alone, except where there has been the grossest admixture of forms. The aerial parts of very different varieties may be closely similar. The separation of a stable variety requires, at the least, the sorting at harvest time of whole plants with their pods attached, paying particular attention to pod form, followed by sorting of the kernels for colour before they are sown the following season. A second season in closely sown plots (at Tozi, about $\frac{1}{100}$ acre, 28 in. between rows, 3 to 6 in. between plants), followed by a repetition of the

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

inspection procedure, appears to purify most types. Some runner and spreading-bunch forms appear to vary from season to season in the vigour or prostrateness of their branching, perhaps depending on the rainfall pattern. These can only be purified by means of progeny rows, which should in addition always be employed, on a considerable scale, in preparing the elements for the mixtures of similar forms desirable as commercial varieties.

The classification here presented will, it is hoped, prove a useful guide in the separation of forms, but it cannot be expected to apply to the crude mixtures which all too often pass for varieties.

Previous classifications.—Most of the older classifications of cultivated groundnuts were based on a primary division of the species into bunch or upright and runner or prostrate forms. The work at Tozi and in Tanganyika had long suggested that this division was inadequate, since there were at least two wholly different sorts of bunch varieties, one of which was clearly akin to the runners and the other not. This led at Tozi to a study of branching habit in relation to other characters, which indicated the more fundamental botanical division outlined under Diagnostic Characters, below.

A search of the literature then showed that the Tozi results fully supported the view of Gregory *et al.* [1], based on the results of Richter [2]. A critical review of the older classifications is therefore not necessary here. The earlier work was reviewed by Chevalier [3], who in developing his own classification was the first to abandon the upright-prostrate dichotomy, though for reasons which now appear inadequate. He found homologous variation in upright and prostrate forms, both presumably of the alternately branched group (see below), in West Africa, but he missed, perhaps through insufficient experience with an extensive living collection, the distinction between the two types of upright groundnuts which would surely have led him to the correct solution.

The classification of Hayes [4], who worked with a collection of forty forms in the Gambia, was based on habit (runner or bunch) and testa colour, and on a number of agronomically unimportant minor characters, many of which showed continuous variation and were studied by a scoring method. They included corolla colour and other floral characters, red coloration of the stem, dimensions and other characters of the leaf and leaflet, hairs on the petioles, and keeping quality of the plucked flowers. Season length and pod characters were not employed. The characters employed made the resulting classification of no practical value, though useful information is recorded on the segregation of these characters in the progeny of a runner × Valencia cross.

Bouffil [5], who had many years' experience with the crop in Senegal, gathered together a range of forms whose field behaviour he studied closely. He too adopted a primary division into upright and prostrate forms, but added a further subdivision based on the presence or absence of seed dormancy, which does in fact separate the two bunch groups.

The herbarium study of Hermann [6] is valuable in clarifying the nomenclature of *Arachis* at the specific level. Hermann, however, followed Chevalier's later views, in part, in handling the systematics of the

forms of *A. hypogaea*, and his classification is therefore defective in the same way.

Diagnostic Characters

Branching pattern.—The morphology of the groundnut plant is adequately described in the admirable paper of Gregory *et al.* already cited [1]. The flowers of the groundnut, whether borne above or below ground, occur exclusively on special branches or inflorescences. Even where a leaf appears to subtend a single flower, there seems always to be a reduced leaf within the axil, showing that the flower is in fact borne on a branch. Where, as is more usual, several flowers are borne in succession on such a branch, each one will be clearly subtended by a reduced leaf or cataphyll. Occasionally the inflorescence branch will grow on, after producing a series of flowers, and will bear a few normal vegetative leaves, but its special status as a flowering and fruiting branch is always clear. (Prévot [7] illustrated such an occurrence.) Usually the reproductive branch is heavily reduced, so that the flowers and later the pods on their stalks appear to arise in a cluster [8, 9].

In addition to these reduced reproductive branches there are normal monopodial branches. In Richter's notation [2] the order n is assigned to the main axis, and first-, second-, and third-order branches are then conveniently indicated as $n+1$, $n+2$, and $n+3$ order branches.

There are two distinct types of branching pattern. In all forms, the main axis gives rise to a number, perhaps five or six, of consecutive, primary, monopodial branches ($n+1$), including the branches produced in the axils of the cotyledons. In the *sequentially branched* forms it then bears one or more reduced fruiting branches, ending with a series of sterile axils. In the *alternately branched* forms, all axils after that bearing the last monopodium are sterile: that is to say there are no reproductive branches on the main stem.

These two types differ also in the mode of branching of the primary monopodia (Fig. 1). In the *sequential* type (reduced fruiting branches borne on the main axis) the primary monopodia ($n+1$) will give rise at their lowest nodes to no, one, or very rarely two secondary branches ($n+2$). They then produce one or more fruiting branches, followed by sterile axils. The structure of the main axis is thus closely followed. Very occasionally, especially in more open stands, a single vegetative branch may form at a high (5th or higher) node of an $n+1$ branch, but this is not common. The general character is sequential in that, on the whole, vegetative branching is not resumed on the primary branches once reproductive branching has begun. This statement, while true for the conditions of Tozi, may not be fully applicable to the conditions of North Carolina, where vegetative branching would seem (from Gregory *et al.* [1]) to be rather more profuse in the 'Spanish' section of the sequentially branched forms. It may be wiser in those conditions to rely on the absence of the alternately branched habit.

In the *alternately branched* type the sequence is quite different. Typically each $n+1$ monopodium produces first two secondary monopodia ($n+2$). It then gives off two reproductive branches and then

again two more vegetative branches. This alternation may be repeated several times before the branch terminates in a series of sterile axils. In higher alternations, a pair of reproductive branches may fail to develop, so that a pair of sterile axils will appear between pairs of vegetative axils; and occasionally the alternation may be three and one, either way. Sometimes one of the lowest $n+2$ branches may fail, leaving a sterile node. The characteristic and contrasting feature is the alternation of vegetative and reproductive branching, which is quite distinct from the sequential branching of the first group.

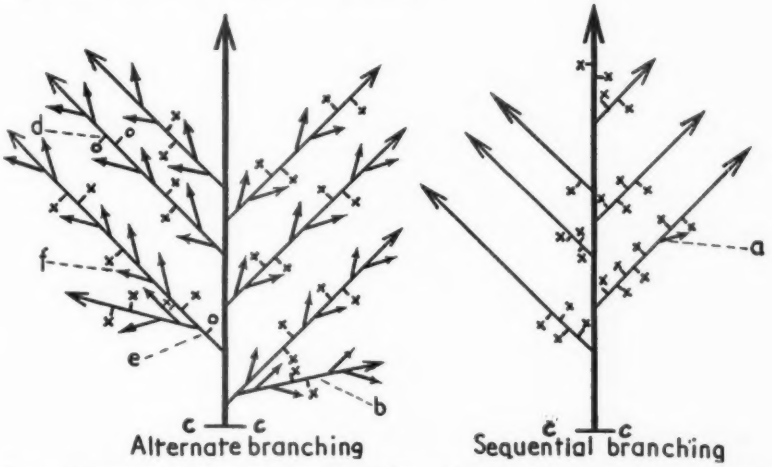

FIG. 1. Diagrams of alternate and sequential branching patterns in groundnuts. (Arrows indicate vegetative apices, crosses reproductive branches; leaves are not shown.)

a: occasional secondary ($n+2$) branch in sequential type;
b: example of alternate branching on secondary branches;
c: position of cotyledons, relative to which the slightly different attachment of the two lowest branches has been exaggerated for clarity;
d: position of pair of aborted fruiting branches between two pairs of vegetative branches;
e: lower vegetative branch of basal pair aborted;
f: 3+1 alternation replacing normal 2+2.

In the Tozi collection, which appears to be fairly representative, the distinction between sequentially and alternately branched varieties coincides with a major division of the species on other grounds.

The sequentially branched forms, which correspond to the Spanish and Valencia types of Gregory's paper [1], are all strictly annual, short-season forms (90–95 days to maturity at Tozi, 105–10 in Tanganyika); they are all lighter green in colour than the alternately branched forms; they all have the upright-bunch habit, with ascending lateral branches which do not overtop the main axis; and as far as is known none of them has seed dormancy. There is a wide range of kernel colour, but where it is brown it is a light brown or bronze shade.

The alternately branched forms, corresponding to the Virginia types of

the United States (in the broad sense), consist of the true runners and the spreading-bunch forms, with a very few types at present tentatively held in an intermediate, prostrate spreading-bunch group for closer study and not included in the classification. They are all longer-season forms, of a more-or-less indeterminate growth period that is subject to environmental restrictions; they may perhaps be weakly perennial. The alternately branching habit is not inappropriate to this mode of growth. They are all dark green in colour, and as far as is known their seeds have dormancy. The kernel colour is almost invariably brown, but the shade is a deep russet brown quite distinct from the paler brown kernels in the sequential group.

The spreading-bunch forms have not previously been clearly distinguished from the upright-bunch types, though Hayes [4] noticed the difference. In the tropics, at any rate, they are marked off from the upright forms by their generally larger size and denser, more bushy habit of growth under comparable cultural conditions. The habit difference results, at least in part, from the difference in branching behaviour: alternate branching gives a more densely leafy structure. The spreading-bunch forms are also darker green and have seed dormancy, which appears to be absent in the upright-bunch group. Finally, the spreading-bunch varieties are longer lived—up to 120 days at Tozi and to 140 in Tanganyika. The two forms are thus agronomically distinct.

In the Tozi collection there are three smaller, alternately branched, bunch types, with somewhat lighter colour, which have at times been confused with upright-bunch forms. One of them may lack dormancy. Their life period is, however, markedly longer than that of the normal upright-bunch type. These three types may come with further study to be placed in an intermediate group, but their number is too small to invalidate the broad division of the species.

This division into sequentially and alternately branched forms, suggested by Gregory and his colleagues, and fully supported by the independent work at Tozi, appears sound, and more satisfactory than Chevalier's division according to pod type, mainly because it concentrates a far higher degree of uniformity into the resulting categories. It is of agronomic significance and therefore likely to prove practically useful.

Growth habit.—All the sequentially branched forms have the upright-bunch habit, but it is possible to distinguish the somewhat more open structure of the Valencia forms from the stricter habit of the Spanish and associated types. The separation between these groups is, however, more reliably made on pod and kernel characters.

The alternately branched section contains prostrate (runner) and upright (spreading-bunch) forms and this difference is of diagnostic importance.

Seed dormancy.—Bouffil [5], after supporting a primary taxonomic division of the species into the prostrate (sub-sp. *africana*) and bunch (sub-sp. *asiatica*) forms, proposed further to sub-divide each of these into forms *tarda* and *praecox*, the former having seed dormancy and the latter not. As has already been indicated, this distinction can be made

between the two types of bunch, when it reinforces the branching differences, but there is some doubt whether non-dormancy occurs in any prostrate form. Bouffil presented no evidence that it does. In the original material used by Stokes and Hull [9] for their breeding studies, dormancy was confined to the runner forms: these workers do not seem at the outset to have possessed dormant-seeded bunch forms. In the progeny of their crosses they did not record the appearance of non-dormant runner forms, though they did obtain bunch progenies with dormancy. Similar results were obtained by Higgins *et al.* [10].

Bouffil's interesting demonstration that the germination of dormant seeds can be accelerated by moistening them with maceration liquid from kernels of non-dormant type deserves further investigation. Maceration fluid of dormant types should also be tried.

Stem, branch, and leaflet characters.—Much attention has been paid to these characters by Chevalier [3], Hayes [4], and Larroque *et al.* [11], but they have not so far appeared sufficiently distinctive either at Tozi or in Senegal [5] to be used in classification. Variation in shape, size, and hairiness between leaflets of the same variety and even on the same plant is as great as any variation which may appear between types. In general, immature leaflets, or those on the lower branches, tend to be smaller, and more ovate or obovate in shape, than those on the main axis or later branches, which are lanceolate or oblong-acuminate. Some Valencia types have noticeably larger leaves, associated with greater height of plant. The tip of the leaf ranges in form from entire, particularly in more-rounded leaves, to acuminate or minutely apiculate in longer leaves. There are variations in the slight hairiness of stems, petioles, rachides, and leaflets: generally the main axis and the leaves on it carry more hairs than the branches and their leaves. In all members of the Valencia group, *sensu stricto*, the stems have a light reddish or purplish tinge. One form, Hong Kong, has recurved leaflets at maturity which give the plant a peculiarly soft appearance. Stipular characters appear to be constant but have not been closely studied at Tozi.

Flower characters.—Throughout the collection, petal colour is golden-yellow in the aerial flowers. Chevalier [3] referred to heritable differences in staminal number, but these have not been studied at Tozi. Hayes [4] used various floral characters in his classification, including the presence of red colour on the standard, but in the writer's view these characters are superficial and not of assistance in reaching an agronomically useful arrangement.

Flowering habit.—The traditional account of flowering in the groundnut represents an aerial flower in which, after fertilization, a gynophore develops outwards and downwards, ultimately carrying the ovary and fertilized ovules into the soil, where the development of the fruit proceeds. In the upright-bunch types, under African tropical conditions, the greater part or even the whole of the commercially useful crop develops on short stalks from flowers formed below the soil surface at the lower nodes of the primary branches. Fruiting stalks (formerly regarded as gynophores but now reported by Smith [12] to be a part of the

ovary itself) may also develop aerially from higher nodes of the stem and branches, particularly under wetter conditions, but in a closely planted commercial crop few if any of these produce fully mature fruits. Bouffil [5] has studied flowering and fruiting habits and has published details of the underground flowers, while Smith [12] has also reviewed the question.

This difference in flowering habit, though of interest and practical importance, is not necessary as a diagnostic character, being associated with the major habit differences already described.

Characters of the pod (shell).—All the characters reviewed below were regarded by Chevalier [3] as of potential use in grouping.

(*a*) *Length.* This is related in most cases to the number of kernels the pod contains, and has been used as a separate diagnostic character only in the subdivision of the sequentially branched varieties with Valencia-type pods (two, three, or four kernels).

(*b*) *Size (diameter).* There is a large range of pod size in groundnuts, from the large pod, which may reach 20 mm. across, of the Virginia bunch type, *sensu stricto*, to small pods down to 8 mm. diameter. In practice, owing to variation in the age of pods on any one plant, and the difficulty of defining the diameter of a somewhat irregular body, this important character is not altogether easy to use. In the present work, pods are described as large, medium-large, medium-small, and small; and these adjectives are used, together with shape differences, to distinguish certain groups in the alternately branched section and in dealing with the upright-bunch groups having brown kernels.

Large pods are those of Virginia bunch or Jumbo types; a typical Valencia would be medium-large; Manyema or Natal Common are medium-small, and certain true Spanish types would be classed as small. The large pods are those of Chevalier's *A. robusta* (in part) or Hermann's *forma macrocarpa*. The small, constricted, Spanish types would seem to correspond to *f. microcarpa* of Hermann *ex* Chevalier. The main Valencia type is the basis of Chevalier's *A. stenocarpa*.

(*c*) *Shape.* Some two-kernelled types have pods which typically are markedly constricted or bent between the kernels, though a slight degree of constriction is common in many groups. The distal end of the pod may be more or less entire, or markedly beaked, with a keel, but use of this character is only safe when it is based on observations of all the pods on an individual plant.

(*d*) *Markings.* Large pods are typically coarsely marked, but otherwise the markings are difficult to define objectively.

(*e*) *Thickness of shell.* The use of this character was advocated by Chevalier. At Tozi, shell thickness is crudely related to size of pod, small pods having thin shells and thick shells being common in the Virginia or Jumbo forms. Thickness has not been useful as an independent character. Bouffil found that the thickness of the pod was related to the rainfall of the place of origin of the variety: in wetter regions groundnuts have thicker pods.

Number of kernels.—In the great majority of forms the kernel number is two. There are no exceptions to this rule in the runner types at Tozi.

In the spreading-bunch and prostrate spreading-bunch types some have three kernels, and typically two-kernelled types occasionally produce a third. In the upright-bunch forms three and four kernels are characteristic of a large number of forms, associated with brown, red, or purple kernels. In the literature, varieties with as many as seven kernels have been mentioned. The varieties fall usefully into two classes with regard to kernel number: those producing typically two kernels and those producing more than two. In all varieties, single-kernelled pods may now and again be found, but no variety is known to the writer in which this is a normal occurrence. Reports of such types have either referred to the Bambarra earth nut (*Voandzeia subterranea*) or have been found to be erroneous.

Kernel colour.—The kernel colour deepens with storage in shell during a period of several weeks after harvest. Observations in the field are therefore often unreliable, particularly in the light brown to russet-brown seeded forms, which always appear pink when freshly harvested. At Tozi, colour has been determined on seed newly shelled-out for sowing, at the end of the dry season and 7–8 months after harvesting.

Varieties with piebald or variegated kernels are found in the *Nambiquarae* group of runners. For the rest, the remaining alternately branched forms have russet-brown seeds, except for the red-seeded Asiriya group, while five colour types occur in the sequentially branched (upright-bunch) forms: namely, creamy white, light brown, dark red, light mauve, and dark purple. This range could be represented by the factorial combination of varying amounts of brown, red, and mauve-blue pigments, except that combinations of blue-mauve with brown have not been seen, though Hector [8] mentioned a violet-brown colour. The light mauve colour has in one instance disappeared in progeny rows, in which russet-brown or dark purple forms were found, so that it was probably the result of chance outcrossing.

Key to the Groups in the Tozi Collection

The choice of criteria.—The primary classificatory division of the cultivated groundnuts is clearly to be based on branching habit. Variation in the two sections thus established shows sharply contrasted patterns. The alternately branched forms vary in respect of growth habit (runner and upright forms), but hardly at all in kernel colour, while only in the broadest sense, and with major exceptions, does their range of pod size and shape resemble that found in the sequentially branched material. In the latter many shades of kernel colour are found, but at Tozi their habit differences (as between Valencia and non-Valencia types) are relatively small.

Contrary to Chevalier's view [3], therefore, the two sections are not homologous. Each section does show internal homologies, however, suggesting that while the two main groups are very different genetically, the variation within each is much less restricted, with little antagonism between characters. The variation at this level is consequently

reticulate in nature, and not naturally amenable to a dichotomous arrangement.

Nevertheless, some order has to be imposed on the material so that groupings may be more precisely specified for a particular purpose. This may be done by selecting a number of criteria, corresponding to elements of variation, and applying them in an arbitrary order of importance. Since there is no 'natural' order of precedence for such elements, each worker will choose those characters and place them in that analytical order which interests him most or which he finds most useful for the purpose in hand.

If in an economic crop clearly identifiable characters of agronomic significance are chosen, the resulting arrangement has some chance of surviving and of being applied, and it is not the less theoretically correct for being useful. It is on these lines that the present classification has been constructed.

In traditional systematic work floral characters are regarded as of primary significance, though their usefulness would seem to be greater at the specific or higher levels. In the present study of intra-specific groupings in *A. hypogaea*, floral characters are not used at all, for the reasons given above. On the other hand, morphological characters, such as habit and branching pattern, and the agronomically interesting characters of the pod and kernel, are readily determinable. It is submitted that the use of these characters has not only given rise to a workable system, but has also revealed at least one element of high taxonomic importance.

Order of subdivision.—To recapitulate, branching habit separates the primary divisions of the species. The alternately branched types are then further divided into spreading-bunch, small spreading-bunch, and runner habit groups, while the sequentially branched forms fall into Valencia and non-Valencia moieties. These habit groupings are then divided on pod shape and size, and kernel colour, to reach groupings which cannot at present be usefully divided further. The total number of groups thus derived is twenty-two.

The characters have been determined on living plants. In the absence of growing reference material, some difficulty might be found in making some of the separations. Further, it is once more emphasized that this grouping has been derived from studies in semi-arid tropical areas. Characters such as season length, and growth and flowering habit, are not unaffected by climatic conditions. In longer seasons and more temperate latitudes, growth continues for a longer time and a higher proportion of the crop is formed from upper nodes, as was shown by Bouffil [5], who grew groundnuts in the region of Paris, by Prévot [7], and by Caubère [13].

Nomenclature.—No useful purpose, either taxonomic or agronomic, would appear to be served by applying formal systematic nomenclature to the groupings, except for the two primary divisions based on branching, which would appear to merit some formal recognition at sub-species level. This will not, however, be undertaken by the present writer. In this paper a series of group names is used which may readily be extended

to cover new material. This is adequate for agronomic purposes and may correspond best to the taxonomic realities.

Field key to the cultivated groundnuts.—

1	Branching alternate (Virginia forms)	2
	Branching sequential (upright-bunch forms)	8
2	Habit prostrate (runner forms)	3
	Habit upright (spreading-bunch forms)	5
3	Kernels variegated red and cream	*Nambiquarae* group
	Kernels not variegated, russet-brown	4
4	Pods large	*Jumbo runner* group
	Pods medium-large	*Kongwa runner* group
	Pods medium-small	*Indian runner* group
5	Kernels red	*Asiriya* group
	Kernels russet-brown	6
6	Plants relatively small, like upright-bunch	*Georgia bunch* group
	Plants larger, normal spreading-bunch	7
7	Pods large	*Virginia bunch* group
	Pods medium-large and smaller	*Matevere* group
8	Kernels typically or frequently more than two	9
	Kernels typically two	13
9	Kernels crimson or purple	10
	Kernels light-brown	12
10	Kernels red	11
	Kernels purple	*Purple Valencia* group
	Kernels white or cream	*White Valencia* group
11	Pods medium-large, stubby	*Valencia* group
	Pods medium, elongated	*Long Valencia* group
	Pods large, tending to Jumbo type	*Large Valencia* group
12	Pods typically beaked and keeled	*Long Manyema* group
	Pods not as above, long Valencia type	*Long brown Valencia* group
13	Kernels white or cream	*White Spanish* group
	Kernels red	14
	Kernels light brown	15
14	Pods beaked and keeled	*Red Manyema* group
	Pods not constricted, beaked, or keeled	*Red Natal* group
15	Pods typically clearly constricted	16
	Pods typically not as above (straight)	17
16	Pods typically beaked and keeled	*Manyema* group
	Pods typically not as above	*Spanish* group
17	Pods medium-large	*Large Natal* group
	Pods medium-small	*Natal-Barberton* group

Notes on certain groups.—Nambiquarae group. These forms correspond to *A. hypogaea* f. *nambiquarae* of Hermann. They are very similar to the Jumbo runner group except for the variegated kernel, which is not found elsewhere in the species.

Jumbo runner group. Material of this group has frequently been rogued from smaller-podded runner material. The pods are of the *macrocarpa* type as found in the spreading-bunch Virginia.

Asiriya group. The only long-season bunch forms having kernels coloured other than russet-brown. These are the forms in which Evans [14] has found material resistant to the spread of rosette disease.

Virginia bunch group. These varieties have large, coarsely marked, and heavily constricted, thick-shelled pods with two russet-brown kernels, commonly used in the confectionery trade. The pods are of the *macrocarpa* or *robustior* forms of Chevalier, Hoehne (quoted by Hermann), and Hermann. The American Jumbo bunch apparently belongs to this group. The Tozi collection contains three such types, of which two were American and the third was found in a village on the Blue Nile.

Matevere group. This is a wide group, which resulted in the work at Tozi from the merging of smaller groups. Closer study is needed to determine whether redivision is called for. The pods are notably smaller than Virginia bunch, and only slightly, if at all, constricted, with two or three russet-brown kernels. The varieties are predominantly African: of 19 in the collection, 6 are from Tanganyika, 3 from West Africa, 5 from the Sudan and Egypt, 1 from Mauritius, and the remaining 4 are from India, the U.S.A., and Brazil. The West African commercial crop seems to consist largely of Matevere material, which has also been introduced to the Blue Nile area of the Sudan by immigrants from Bornu and other parts of West Africa.

White Spanish group. The pods are rather more coarse than in the normal Spanish, with something of a Manyema appearance.

Purple Valencia group. Except for kernel colour these forms are essentially Valencias. The same applies to the *White Valencia* group.

Red Natal group. This is a somewhat mixed group. The pods are not beaked, but resemble the Natal type, being medium to medium-small in size and not constricted. The variety Red Spanish (*ex* U.S.A.) is included here because, at Tozi, it does not show the typical Spanish constriction between the kernels.

Valencia group. A remarkably uniform and natural group corresponding to the Peruvian form of Dubard (1906, quoted by Chevalier [3]). The stems and branches have a typical reddish tinge, which does not occur in the *long Valencia* type. The pod is characteristic, with a stubby profile: the two to four or more kernels are markedly flattened at their faces of contact. Some typical Valencia varieties tend to a high proportion of pods with but two kernels. Valencia is known in some areas as Virginia bunch.

Spanish group. These are the *microcarpa* forms of Chevalier, which include the smallest-podded of all cultivated groundnuts. The name Spanish is used by some American workers as if it applied to all brown-kernelled upright bunch forms having two kernels, but all

material derived from the U.S.A. under the name of Spanish has the typical constricted pod and is quite distinct from the Natal and Manyema types described below.

Manyema group. These all have a beaked and keeled pod with bold markings and a constriction between the kernels. Manyema is a district in the Belgian Congo towards Lake Tanganyika, formerly much affected by the slave traffic from the Tanganyika coast.

Natal Common-Barberton group. The pod here is typically entire and straight, without constriction. Natal Common itself is much grown in the Union of South Africa, and was for some time the principal production variety of the Overseas Food Corporation in Tanganyika. Barberton, which is very similar in appearance, was bred from Indian material at the former Barberton station of the Empire Cotton Growing Corporation.

Large Natal group. This was established to contain material isolated at Tozi from other varieties during the progress of purification, and from progeny-row testing with Natal Common. The kernels are twice the weight of standard Natal kernels, but fewer of them appear to be produced per plant.

Summary

An independent study of a collection of over two hundred forms of cultivated groundnuts, in Tanganyika and in the central rainlands of the Sudan, confirmed the observation of earlier workers that there are two entirely different patterns of branching in the species. In one type, vegetative and reproductive secondary branches alternate, usually in pairs, on the primary branches; in the other type, a continuous sequence of nodes on the primary branches bears reproductive branches, and later nodes are sterile. Vegetative secondary branches are rare in this type except at the first or second nodes of the primaries.

The distinction between the alternately sequentially branched forms corresponds with a major division of the species on grounds of habit, season length, colour of foliage and of testa, and seed dormancy. The two sections thus established are not mutually homologous, though the variation of each is internally homologous. They are further divided in the present work, on the bases of habit, kernel colour, and pod size and shape, to give a classification into twenty-two groups which are readily recognizable in the field as separate entities. A field key and descriptions of some of the groups are given.

No attempt is made to provide a taxonomic evaluation of the major division, but it clearly indicates that the previous systematic subdivisions of the species need to be re-examined.

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(*Received 12 April 1955*)

THE COMPOSITION AND NUTRITIVE VALUE OF CERTAIN FEEDINGSTUFFS IN NIGERIA. II. CONCENTRATES

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In a previous communication [1], results were given for the proximate chemical constituents of various types of roots and tubers, and a few green leaves, grown under the conditions prevailing in southern Nigeria. It was shown that these succulent crops are mainly sources of carbohydrate food, and that their rinds or peelings contain relatively high concentrations of non-carbohydrate nutrients and are, therefore, suitable sources of supplementary feedingstuffs for domestic livestock.

Grains of cereals, legume seeds, and oil-bearing seeds and their by-products supply greater energy and more balanced nutrients per unit weight than do the succulent materials. Many of the legumes, and the residual cakes and meals obtained after oil-extraction, provide vegetable proteins which are employed in livestock feeding to balance the carbohydrates contained in the succulent materials and the cereals. Further, the farming economy of northern Nigeria is based chiefly on cereals and legumes (Guinea corn, millet, groundnuts, and cow-peas) and on livestock. The grains are therefore cheaper than the succulent materials as sources of nutrients for animals, particularly in northern Nigeria.

Experimental.—The methods of collection, sampling, treatment, and analysis of the samples, with details concerning the construction of the tables, and the calculation of values, have already been described [1].

Results

Results of analyses of the dry matter of all samples are shown in the columns headed 'A', Table 1. In Table 2 the digestible nutrients calculated from these values are recorded in the columns headed 'B', while the columns headed 'C' give the nutritive ratio, the protein and starch equivalents, and the total digestible nutrients (TDN) per 100 lb. of the fresh food as fed to animals, all calculated from the digestible-nutrient columns.

Cereals.—It will be observed in Tables 1 and 2 that acha grain (*Digitaria exilis* Stapf) was inferior in nutritive value to the other cereals analysed. While the TDN appeared only slightly lower than that of Guinea corn, the crop was appreciably inferior to the latter and to the other cereals analysed in the proportion in which the nutrients occurred. It had, for example, the lowest values for digestible crude protein and protein equivalent, and therefore the widest nutritive ratio (1 : 17·8). Its ash content was low.

The higher TDN value recorded for bulrush millet (*Pennisetum typhoideum* Stapf and Hubbard), compared with Guinea corn (grain sorghum), is partly explained by the higher amount of digestible oil in

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

TABLE 1. *Composition of Feedingstuffs in Nigeria*

No.	Feedingstuff: Common name	Feedingstuff: Scientific name	A Average chemical composition as determined. Per cent. of dry matter: Dry matter	Crude protein	True protein	Ether extract	Crude fibre	Nitrogen-free extractives	Total ash	Silica-free ash
	CONCENTRATES		%	%	%	%	%	%	%	%
1	Acha grain	*Digitaria exilis*	85·3	7·42	6·66	1·26	0·35	88·2	2·74	0·80
2	African locust bean, seed	*Parkia filicoidea*	94·3	30·38	27·13	20·30	8·82	35·1	5·38	5·28
3	African locust bean, seed and powdery material	,, ,,	91·9	19·28	15·82	10·60	11·15	52·6	6·42	6·30
4	African locust bean, whole fruit	,, ,,	92·9	12·71	11·13	6·75	18·03	49·3	6·21	5·95
5	Bambara groundnut (decorticated)	*Voandzeia subterranea* ,, ,,	92·1	21·14	20·43	6·54	5·08	53·5	3·78	3·61
6	Bambara groundnut (undecorticated)	,, ,,	95·2	17·58	10·77	5·26	13·66	54·8	5·24	4·04
7	Blood meal, pure, dried		89·5	88·48	85·52	1·20	0·36	4·0	5·98	4·15
8	Blood meal mixture		92·9	33·72	30·60	2·56	23·57	29·9	10·25	2·98
9	Coconut (edible portion)	*Cocos nucifera*	89·8	10·97	9·77	65·90	7·22	13·6	2·34	1·34
10	Cocoa beans	*Theobroma cacao*	47·2	14·28	10·60	42·84	8·96	29·3	4·59	3·52
11	Cotton-seed	*Gossypium* spp.	94·6	28·47	26·85	14·05	21·61	31·1	4·75	4·44
12	Cow-pea seed	*Vigna unguiculata*	91·3	24·67	22·75	2·46	1·81	67·3	3·78	3·71
13	Green gram seed	*Phaseolus aureus*	88·4	28·46	28·21	0·99	5·15	60·2	5·18	4·93
14	Groundnut seed (decorticated)	*Arachis hypogaea*	95·1	27·20	24·88	50·92	9·61	9·5	2·79	2·64
15	Groundnut seed (undecorticated)	,, ,,	92·9	21·66	20·71	39·09	21·14	15·4	2·72	2·65
16	Groundnut cake (decorticated)	,, ,,	90·4	51·41	47·64	10·16	4·64	28·3	5·51	3·81
17	Guinea corn grain (grain sorghum)		88·4	15·03	14·23	3·25	2·94	76·2	2·60	2·36

18	Lima bean, shelled	*Phaseolus lunatus*	95·6	27·20	24·12	0·86	5·20	61·2	5·49	5·11
19	Lima bean, unshelled	,, ,,	95·4	18·80	17·88	0·55	17·50	59·2	3·96	3·74
20	Maize, yellow, grain	*Zea mays*	90·4	10·65	10·16	4·09	1·32	82·6	3·68	3·13
21	Millet, bulrush, grain	*Pennisetum typhoideum*	88·8	9·02	8·00	4·99	0·66	83·2	2·13	1·09
22	Mucuna seed, black var.	*Mucuna* spp.	94·2	28·59	27·69	0·67	9·49	57·2	4·01	3·98
23	Mucuna seed, white var.	,, ,,	94·7	27·37	26·69	1·11	6·54	61·0	4·03	3·97
24	Palm kernel cake	*Elaeis guineensis*	91·6	20·40	20·07	8·32	9·02	56·6	5·67	2·69
25	Pigeon pea, *ex* Ibadan	*Cajanus cajan*	94·7	23·77	21·46	1·11	7·49	62·4	5·24	4·67
26	Pigeon pea, *ex* Trinidad	,, ,,	94·7	23·79	21·48	1·06	5·76	64·1	5·25	5·05
27	Rice grain with hull (paddy or rough rice)	*Oryza sativa*	93·9	11·17	10·70	1·89	9·02	73·5	4·47	1·59
28	Rice grain, hull removed (brown rice)	,, ,,	94·4	12·51	11·92	0·21	0·19	85·7	1·38	1·18
29	Rice grain, polished (polishings,&c.,removed)	,, ,,	90·1	9·10	..	0·14	0·31	89·9	0·58	0·38
30	Rice grain, husk and bran mixed	,, ,,	87·1	8·04	7·54	1·21	44·15	32·7	13·90	3·23
31	Rice, bran with little husk	,, ,,	89·0	7·62	..	7·59	36·62	36·9	11·30	4·32
32	Soya-bean	*Glycine soja*	93·2	44·08	40·81	19·10	5·71	26·1	5·06	4·40
33	Sunflower seed	*Helianthus annuus*	94·2	16·01	14·15	33·39	28·09	19·7	2·86	1·66
34	Sunn-hemp seed	*Crotalaria juncea*	96·0	40·27	31·69	1·41	9·99	42·7	5·61	4·56
35	Water-melon seed, Bara var. (unshelled)	*Citrullus vulgaris*	88·0	24·36	21·62	35·36	31·63	4·5	4·15	3·42
6	Water-melon seed, Bara var. (shelled)	,, ,,	91·9	34·48	30·91	46·74	8·24	4·4	6·17	5·85
37	Water-melon seed, Serewe var. (unshelled)	,, ,,	93·2	23·55	22·09	44·76	22·48	5·3	3·87	2·91
38	Water-melon seed, Serewe var. (shelled)	,, ,,	93·4	30·22	28·58	57·06	3·03	6·0	3·69	3·43

TABLE 2. *Calculated Nutritive Values of Feedingstuffs in Nigeria*

No.	Feedingstuff / Common name	B Calculated digestible nutrients Per cent. of dry matter: Digestible crude protein	Digestible true protein	Digestible ether extract	Digestible fibre	Digestible nitrogen-free extractives	C Calculated from digestible nutrients: Nutritive ratio	'V' Correction factor	Per 100 lb. of food: Protein equivalent	Starch equivalent	Total digestible nutrient
	CONCENTRATES	%	%	%	%	%	1:	%	%	%	%
1	Acha grain	4·53	4·06	0·83	0·35	78·5	17·8	..	3·67	..	72·8
2	African locust bean, seed	24·61	21·97	12·99	6·35	34·1	2·9	97	21·97	86·8	88·9
3	African locust bean, seed and powdery material	15·62	8·24	5·40	12·05	42·9	4·3	..	10·96	..	76·1
4	African locust bean, whole fruit	12·81	9·41	6·78	8·03	51·0	5·8	97	10·32	78·7	80·9
5	Bambara groundnut (decorticated)	17·12	16·75	4·51	3·20	49·3	3·7	..	15·60	.	73·4
6	Bambara groundnut (undecorticated)	14·24	8·56	4·89	4·64	10·4	1·9	..	10·85	..	38·5
7	Blood meal, pure, dried	84·92	82·10	1·20	0·07	1·0	0·1	100	74·77	75·0	79·4
8	Blood meal mixture	..	..	..	..	..	..	..	..	..	..
9	Coconut (edible portion)	9·21	8·21	65·90	3·03	11·5	18·0	..	7·82	..	15·4
10	Cocoa beans	5·28	3·92	38·56	3·58	26·1	22·4	..	2·17	..	57·5
11	Cotton-seed	21·07	19·87	12·93	13·83	18·4	2·9	94	19·36	73·9	77·9
12	Cow-pea seed	20·33	13·66	1·70	1·14	61·9	3·3	97	17·76	60·7	79·5
13	Green gram seed	25·90	25·67	0·90	2·58	53·0	2·2	97	22·79	70·2	73·8
14	Groundnut seed (decorticated)	24·75	22·64	46·34	4·81	8·3	4·4	99	22·54	139·4	135·2
15	Groundnut seed (undecorticated)	17·54	16·78	36·35	7·19	2·9	4·8	86	15·94	91·2	101·7
16	Groundnut cake (decorticated)	46·78	43·35	9·25	2·32	24·9	1·0	98	40·73	84·5	85·7
			8·68	3·15	3·94	67·8	8·3	..	7·89	..	74·9

17	Guinea corn grain (grain sorghum)	9·17	8·68	2·15	2·94	67·8	8·3	..	7·89	..	74·9
18	Lima bean, shelled	22·30	19·78	0·86	5·20	56·9	2·9	..	20·11	..	82·6
19	Lima bean, unshelled	15·42	14·16	0·37	15·23	55·1	4·6	..	14·35	..	82·6
20	Maize, yellow, grain	8·20	7·82	3·68	0·75	76·8	10·5	100	7·24	84·1	85·0
21	Millet, bulrush, grain	6·40	5·68	3·64	0·35	76·5	13·3	95	5·36	76·4	81·2
22	Mucuna seed, black var.	24·59	23·81	0·43	4·75	53·2	2·4	..	22·78	..	78·7
23	Mucuna seed, white var.	23·54	22·95	0·71	3·27	56·7	2·6	..	22·02	..	80·6
24	Palm kernel cake	16·48	16·22	6·32	4·87	49·2	4·2	100	14·98	77·7	77·7
25	Pigeon pea, *ex* Ibadan	20·44	18·46	0·71	3·75	58·0	3·1	..	18·42	..	79·4
26	Pigeon pea, *ex* Trinidad	20·46	18·47	0·68	2·88	59·7	3·1	..	18·45	..	80·1
27	Rice grain with hull (paddy or rough rice)	8·49	8·13	1·63	3·07	64·6	8·4	..	7·81	..	75·0
28	Rice grain, hull removed (brown rice)	9·51	9·06	0·16	0·04	78·0	8·3	100	8·77	82·4	83·0
29	Rice grain, polished (polishings,&c.,removed)	..	..	..	..	..	..	..	..	..	..
30	Rice grain, husk and bran mixed	5·47	5·13	1·00	12·36	24·9	7·2	..	4·61	..	39·1
31	Rice, bran with little husk	5·18	..	6·30	10·25	28·0	10·1	..	..	..	57·6
32	Soya-bean	39·23	36·32	16·81	4·17	17·5	1·5	98	35·22	90·5	92·0
33	Sunflower seed	13·77	12·17	21·37	14·05	18·3	5·9	92	12·22	83·9	88·7
34	Sunn-hemp seed	34·63	27·26	0·90	5·00	39·7	1·4	96	29·70	73·0	78·1
35	Water-melon seed, Bara var. (unshelled)	22·17	19·67	32·18	15·82	3·9	4·2	..	18·41	..	100·6
36	Water-melon seed, Bara var. (shelled)	31·38	28·13	42·53	4·12	3·9	3·4	..	27·36	..	124·1
37	Water-melon seed, Serewe var. (unshelled)	21·43	20·09	40·73	11·24	4·7	5·1	..	19·34	..	120·2
38	Water-melon seed, Serewe var. (shelled)	27·50	26·01	51·92	1·52	5·3	4·6	..	24·99	..	141·1

the former (3·64 per cent. as against 2·15 per cent.). Guinea corn was nevertheless superior to millet in protein, expressed as either digestible crude protein or protein equivalent, in ash, and in fibre, with a narrower nutritive ratio.

Maize (*Zea mays* Linn.) was somewhat richer in nutrients than Guinea corn, being appreciably higher in TDN, ash, and oil, but somewhat lower in digestible protein, which resulted in a wider nutritive ratio. Both bulrush millet and Guinea corn compared well with maize in oil content, the millet being slightly richer than maize in this constituent. Paddy rice (*Oryza sativa* Linn) compared well with Guinea corn in TDN, digestible crude protein, protein equivalent, and nutritive ratio. It was lower in digestible oil and ash than Guinea corn, and, not being hulled, had a higher amount of crude fibre.

Leguminous and oil seeds and nuts.—The seed of the African locust bean (*Parkia filicoidea* Welw.) is a protein concentrate which showed a narrow nutritive ratio (1 : 2·86), high TDN (88·92 per cent.), and crude protein (30·38 per cent.), and a protein equivalent of about 22 per cent. The seed was also rich in oil. It was as high in protein as decorticated groundnut, and higher in this nutrient than undecorticated cotton-seed. Its narrower nutritive ratio when compared with the decorticated groundnut may have been due to its lower oil content.

The sample of the edible portion of the coconut (*Cocos nucifera* Linn.) that was analysed had somewhat high values for protein, oil, and crude fibre. Owing to its high oil content, coconut is not usually included in livestock rations except in very small quantities. For the same reason, but more particularly because of its theobromine content, cocoa bean (*Theobroma cacao* Linn.) is not of importance in animal feeding. Its chemical composition is nevertheless of interest since it can be used as a stimulant. The defatted, theobromine-free cake, on the other hand, would be a valuable protein concentrate.

The sample of cotton-seed (*Gossypium* spp. Linn.) analysed appeared low in oil and high in protein. It could therefore be fed to cattle without danger of scouring. The high TDN content of groundnut (*Arachis hypogaea* Linn.) was due to the high amount of digestible oil (46·34 per cent.). The ash was low, but the fibre somewhat high, while the protein agreed with that presented by Woodman [2]. Soya-bean (*Glycine soja*, Sieb. and Zucce.) was above the average in protein, and somewhat high in fat, TDN, crude fibre, and soluble carbohydrate, but only average in ash content. While the protein and the crude fibre of sunflower seed (*Helianthus annuus* Linn) were only average, the fat content was appreciably above the average, giving rise to a high TDN. The high fat content also accounted for a somewhat wide nutritive ratio.

Of the two varieties of water-melon seed (*Citrullus vulgaris* Schrad.), the 'Bara' variety was richer in protein, ash, and crude fibre, and poorer in oil, than the 'Serewe' variety. The latter contained a higher TDN, a lower protein equivalent, and a wider nutritive ratio. Both, however, were important sources of protein and oil.

The decorticated groundnut cake was rich in oil and protein, but somewhat poor in fibre and ash. The high values for starch equivalent

and TDN were probably due to the rather large amount of oil left in the residual cake by the expeller method of extraction adopted in the Kano mills. A similar explanation applies to the palm-kernel meal (*Elaeis guineensis* Dacq.), which also showed a somewhat high TDN and starch equivalent.

Bambara groundnut (*Voandzeia subterranea* Thouars) was a fairly good source of digestible protein, ash, and TDN, with a narrow nutritive ratio. Apart from the high fibre content, the undecorticated nut was only slightly inferior to the decorticated one.

Cow-pea seed (*Vigna unguiculata* Walp.) was somewhat high in respect of TDN, protein, fat, and ash. It was low in crude fibre and high in soluble carbohydrate. Green gram (*Phaseolus aureus* Linn.) was high in protein, fibre, and ash, and low in TDN. The nutritive ratio was narrow. It compared well with Lima bean (*Phaseolus lunatus* Linn.) in nutrient content. Of the two varieties of pigeon-pea (*Cajanus cajan* Druce), the Trinidad variety appeared consistently somewhat superior to the Ibadan variety in all the constituents examined except in oil.

In general, it would appear that when compared with those of other countries [3] some of the oil-seed crops grown in Nigeria, as presented in these tables, were high in oil and fibre, somewhat low in protein, and average in mineral matter. This applied particularly to groundnuts, soya-beans, sunflower seed, cotton-seed, and coconut.

Discussion

The Cereal Concentrates

Digitaria exilis Stapf (acha grain or 'hungry rice').—Acha grass, a small millet, is indigenous to West Africa, where it is grown both for its small, yellow grains and for its straw. The latter is used in many ways; for example, for filling mattresses and pillows, for mixing with building clay, and commonly for fodder. In Nigeria acha grain forms the staple cereal food of the hill tribes of Jos and Bauchi, where the poor, sandy soil will not support the growth of some of the more popular cereals. It is also grown in various parts of Sierra Leone, in French and Portuguese Guinea, and in Togoland.

The grain is used as porridge and is prepared in various other forms for human consumption. Both the grain and the straw are suitable food for ruminants. Acha grain is a good concentrate feed for pigs and poultry, especially in those areas of poor soil where the crop is more economically produced than any other cereal. Acha was inferior in protein content to the other cereals analysed (millet, Guinea corn, maize, and rice), and it was very poor in ash. It therefore needs to be balanced with both protein and mineral supplements when fed to animals.

Pennisetum typhoideum Stapf and Hubbard (bulrush millet or gero).—Bulrush millet is the staple cereal in those regions of Nigeria which border on the Sahara desert, where the climate is too dry for dependable Guinea-corn harvests. It is drought-resisting, and will germinate with less moisture in the soil than almost any other crop. It is capable of growing and maturing quickly under a short period of rainfall. There are

various varieties of this millet, classified according to whether they are early or late maturing, smooth or bristly, &c.

The results presented in the tables compare well with those given by the Imperial Institute in 1908 [4] for analyses of samples of bulrush millet from Nigeria. The grains are a fairly good source of protein, lower than Guinea corn but higher than acha in their content of this nutrient. The seeds of gero form good food for poultry. They can also be used as cattle feed.

Sorghum spp. (Guinea corn or great millet).—Guinea corn is by far the most extensively cultivated cereal crop in Nigeria and the Cameroons. During the 1950–1 season an area of over 4 million acres was planted, giving a yield of just under 2 million tons of threshed grain [5]. Over 98 per cent. of this quantity was produced in the Northern Region, principally in the provinces of Kano, Bornu, Adamawa, Katsina, and Sokoto.

Guinea corn is a dry-climate crop, and does best in districts where the rainfall is too low for maize or upland rice but higher than is required for growing bulrush millet. Although Guinea corn can be grown in areas with a rainfall as low as 20 in. per annum, it thrives best in districts where the rainfall is between 25 and 50 in. It requires light but regular rains during its period of growth, and hot dry weather for the seeds to ripen.

Sorghum grain is a valuable starchy food for man and concentrate for livestock. The sample analysed was richer than maize in protein, but lower than maize in soluble carbohydrates, oils, and mineral matter. According to Dalziel [6, p. 545] the biological value of the proteins of Guinea corn produced in northern Nigeria is low. The ash, though rich in phosphorus, is nevertheless deficient in calcium, sodium, potassium, chlorine, and iron.

Guinea corn is widely used in feeding livestock. Some varieties are specially grown in northern Nigeria as feed for horses. The smaller-seed varieties and the bran also afford excellent feed for all classes of livestock.

Zea mays Linn. (maize or Indian corn).—Maize is predominantly the cereal crop of the south, as sorghum and millet are those of the north of Nigeria. The crop is, however, cultivated to some extent throughout the country except in Sokoto and Adamawa Provinces [5]. In 1950–1 it was grown on an area of about 2 million acres of land, with a production of over 744,000 tons or about 30 million bushels (1 bushel = 56 lb.) of shelled grain [5].

Maize is a widely used human food in Nigeria. The fresh grains are eaten, roasted or boiled on the cob. The ripe grains are cooked in combination with pulses, or milled and taken as porridge (*ogi* or *eko*).

Maize is also a highly suitable and palatable feedingstuff for all classes of livestock, because of its high content of readily soluble and digestible starch. In Nigeria it offers a somewhat cheap source of feed for livestock production, particularly for the rapidly developing pig business. It is much liked by poultry: the local indigenous fowl is raised almost wholly on maize grains.

Maize is richer in oil than any other cereal except oats and millet. It is high in protein and low in fibre and ash. The non-starchy nutrients of

maize are concentrated in the germ, which forms about 11 per cent. of the whole grain. According to Earle *et al.* [7] the germ of maize contains about 35 per cent. oil, 19 per cent. protein, and 10 per cent. ash. The white and yellow varieties of maize are similar in composition, except that the latter is richer in carotene, the precursor of vitamin A.

Oryza sativa Linn. (rice).—Rice cultivation on any appreciable scale was commenced in Nigeria only during World War II, importation from the Far East through Britain being no longer possible, and the production of the crop is still rapidly increasing. The provinces of Niger, Sokoto, Benue, Bauchi, and Ilorin in the north, of Ogoja and Cameroons in the east, and of Abeokuta and Ijebu in the west, are the main producing areas. Four hundred thousand acres of rice, yielding about 250,000 tons, were cultivated in 1950–1 [5]. The development of plantations both by the Colonial Development Corporation and by the Regional Production Development Boards has contributed to the rapid expansion of rice cultivation in Nigeria within the past few years. Yields of up to 2 tons of paddy per acre are being obtained by improved cultural methods. Both types of rice—swamp and upland—are produced in Nigeria, the upland varieties being more common in the south while the swamp variety is grown along river banks and valleys, more particularly in the north where natural flooding assists its cultivation.

Paddy or rough rice may be used whole as a feedingstuff for poultry and for other farm animals. Usually, however, it is milled to remove the husks and to produce 'polished' rice for human consumption and bran for livestock feeding. In Nigeria the quality of the milling products tends to vary with the type and size of the milling machinery and the capital put into the business. Frequently the milling process is carried out by the standard machine methods, but in some mills the various phases of the process are indistinct—for example, when the removal of the hulls and the germ to produce 'white' rice is carried out in one operation. The waste product here is a mixture of pulverized hulls and germ bran, which contains a high proportion of fibre and of silica, and is of low digestibility and nutritive value. In the standard machine process, however, the removal of the rice hull from the paddy, to yield 'brown' rice, is a separate operation from the removal of the germ to produce 'white' rice, which when polished yields the so-called 'polished' rice.

The husk or covering coat obtained from paddy rice has no nutritive value, as it is high in crude fibre and in silica. It is used mostly as a source of fuel or packing material. Rice bran from 'brown' and 'white' rice is a valuable cattle food, as may be seen in Tables 1 and 2. This fraction of the waste product contained about 56 per cent. of the crude protein, 56 per cent. of the fat, and 68 per cent. of the minerals present in 'brown' rice.

It will be observed from the Tables that in the production of 'brown' rice from paddy there is an appreciable removal of the crude fibre and silica, an increase in the total digestible nutrient, nitrogen-free extractives, crude and true proteins, and a decrease in the ether extracts and mineral matter. The removal of the germ and polishings which results in 'white' and 'polished' rice, on the other hand, is accompanied by a

loss of the crude protein, oil, ash, and silica, and a rise in the fibre and nitrogen-free extractives.

Kik and his associates [8, 9] have shown that the bran of commerce contains a substantial portion of the thiamine, riboflavine, nicotinic acid, pantothenic acid, and pyridoxine contained in 'brown' rice. Since the aleurone layer and the polishings are incompletely removed in the local milling, the locally produced bran will be relatively lower in these vitamins as well as in protein, oil, and total digestible nutrient, and much higher in fibre content. It will appear inferior as a feeding concentrate to the bran of commerce.

The samples of upland rice analysed were high in protein (higher than is common in swamp rice), but low in oil, fibre, and ash. Upland rice is a valuable source of soluble carbohydrate, and it is high in total digestible nutrients and starch equivalent. Generally speaking, rice grain is low in calcium, phosphorus, magnesium, and iron.

The Protein Concentrates

Parkia filicoidea Welw. (African locust bean). Vernacular names: *dorowa* (Hausa), *irugba* (Yoruba), *ogiri-igala* (Ibo).—The African locust bean is fairly widely distributed throughout the natural grasslands of northern Nigeria. It is a tree of medium size, spreading, with compound leaves and small, numerous leaflets. The fruits are represented by bunches of pods which form the most nutritive part of the plant. Each pod, which may vary in length between 5 and 11 in. according to soil fertility, contains a yellow, dry, and powdery pulp, inside which is embedded a number of dark brown or black seeds.

The yellow, mealy pulp is sweet to the taste, and it is made into 'dorowa', a carbohydrate food usually taken by the Hausas along with cereal grains, in meat stew or soup. The seeds are sometimes boiled for about 24 hrs. and made into 'daudawa' cakes, another popular Hausa food.

All parts of the fruit, including the pod, the mealy material, and the seeds, constitute valuable cattle food. The seeds are rich in fat, protein, and ash, and high in crude fibre. They compare well with decorticated groundnut seed in protein and fibre content, and are much higher in ash but appreciably lower in oil than the groundnut. The seeds form a valuable protein concentrate, particularly during the dry season when other sources of supplementary food for livestock in northern Nigeria are scarce.

The mealy material in which the seeds are enclosed is higher in carbohydrate than in protein, with a high content of crude fibre. This portion could serve as a good source of carbohydrate concentrate for all classes of livestock, but the proportion fed to pigs and poultry should not be too high owing to the limited ability of these animals to digest fibre.

The composition of *Parkia filicoidea* reported in this paper agrees fairly well with the analyses of Gold Coast samples made in 1921 at the Imperial Institute [10]. No part of the fruit has been found to contain cyanogenetic glycosides [10].

Voandzeia subterranea Thouars. (Bambara groundnut. Also known as earth pea, Madagascar or stone groundnut.)—Bambara groundnut is a leguminous plant which is native to Africa. It is widely grown in the drier part of Nigeria and the Cameroons, mainly for local consumption. About 41,000 tons of shelled nuts were produced from an area of some 120,000 acres in 1950–1 [5]. It is also commonly cultivated on the coastal plains of the Gold Coast and other parts of Africa.

Voandzeia is a short-lived creeping herb, about 1 ft. high, with branched stems and compound leaves of three leaflets; its paired flowers give rise to fruits that turn underground in a similar way to those of the groundnut. It is cultivated in the same way as the groundnut, which it closely resembles, although it is slightly more bushy and forms less cover during its growing period.

The pods are hard and spherical, wrinkled when dry, and each pod contains one or two seeds; varieties with three seeds to the pod also occur. The colour of the seeds may vary from black to white, or the seeds may be mottled with various colours.

Bambara groundnut is not an oily seed, since it contains only about 6 per cent. of ether extract. It differs in this respect from the groundnut, to which it is also somewhat inferior in its protein content.

The nut is a fair source of protein and carbohydrate. It is low in fibre, and could thus be used to replace cow-peas or other pulses (apart from groundnut and soya-bean, to which it is inferior) as a protein concentrate. It can be fed successfully to poultry and pigs. It is a feedingstuff that may profitably be raised from poor soils, unfavourable for groundnut production.

Cocos nucifera Linn. (coconut).—The coconut is the seed of the coconut palm, one of the most important oil-bearing perennial plants of the world. The palm grows naturally, or it may be established in plantations or gardens, near the sea coast in tropical countries. It does equally well inland in well drained, loamy soils of the tropics. The plant grows best in areas where there is an annual rainfall of between 40 and 50 inches.

The sample of the endosperm of coconut reported here was fairly rich in protein and oil, and somewhat high in crude fibre, but low in ash. Its oil content was too high to make it a suitable source of protein food for livestock, although the endosperm is fed whole, in small quantities, as a protein supplement to poultry. Coconut is also rich in carbohydrates, a high proportion of which are sugars and cellulose with only a negligible amount of starch [11].

Theobroma cacao Linn. (cocoa beans).—The cocoa bean appears too high in oil to be a suitable feedingstuff, except when included in compound rations in very small quantities. Extraction of the fat might reduce this danger, but the theobromine content of the defatted meal (2–3 per cent.) would still prevent its incorporation in large quantities in compound rations.

Gossypium spp. Linn. (cotton-seed).—About 930,000 acres of Nigerian farming land were devoted to cotton growing in 1950–1, with a total production of about 136,000 tons of seed cotton. Although the crop is

grown primarily for its fibre, the seed forms one of its most important by-products.

In northern Nigeria cotton-seed is commonly soaked in water and fed to cattle and sheep as a supplementary feed. It is usually mixed with green or dry fodder, Guinea-corn bran, beans, and legume hay. Unless the seed is well mixed with more palatable foods, it is sometimes very difficult to get cows to take it. Too large an amount should not be fed to livestock as the high oil content may cause scouring. Cotton-seed and its by-products, when fed to dairy cattle, tend to produce butter-fat of high melting-point, and hard body-fat when fed to fattening animals.

Cotton-seed also contains the pigment gossypol, a toxic phenolic compound, which has an inhibiting effect on the enzymes pepsin and trypsin in the alimentary tract and which tends to cause constipation in livestock. Calves and young sheep, and pigs and poultry of all ages, are much more susceptible to gossypol poisoning than are mature cattle and sheep, so that it is inadvisable to feed cotton-seed and its by-product to them. Horses may be fed the seeds in small quantities. Soaking reduces the toxic effects of gossypol, and treating the seed or meal with 3–4 lb. of ferrous sulphate per 100 lb. of the seed makes it safe for pigs [3, p. 548].

The sample here analysed was a good source of protein and ash, but high in crude fibre. This also would make it unsuitable for poultry and pigs.

Arachis hypogaea Linn. (groundnut. Also known as earth-nut, peanut, monkey-nut, &c.) In Nigerian vernaculars, e.g. *epa* (Yoruba), *gya'da* (Hausa), *okpa* (Ibo.)—The groundnut is one of the most important sources of edible vegetable oils of commerce, and it is cultivated principally for this purpose. World output reached just over 10 million tons of shelled nuts in 1949, of which Nigeria, with a production of over 750,000 tons, was the fifth-largest producing country in the world. Notwithstanding the fact that a considerable amount of Nigerian production is consumed locally, export of the crop has steadily increased in proportion to Nigeria's total exports within the past few years, rising from about 14 per cent. in 1938 to about 24 per cent. in 1949 [12].

The groundnut is rich in proteins of high biological value, which form an excellent source of the essential amino acids, all of which, except lysine, methionine, and perhaps tryptophane, occur in optimum levels for growth, reproduction, and lactation. Several investigators [13–15] have shown that the biological value of groundnut protein is among the highest of the vegetable proteins, when it is used in the rations of beef and dairy cattle, dogs, rats, pigs, and poultry, being almost equal to that of casein from cow's milk. The amino-acid composition of groundnut protein is such as to make it particularly suitable for supplementing the deficiencies of cereal proteins. It is readily digestible, and this adds to the high nutritive value of the groundnut.

The carbohydrate content of the groundnut is relatively low, being under 10 per cent. of the whole nut in the sample analysed. The nut has a relatively high proportion of fibre. The most valuable constituent of groundnut, however, is its oil, which comprises about 50 per cent. of

the total kernel. The content of oil has been stated to depend on the richness of the soil and the condition of cultivation rather than on the variety grown [16], the percentage being greater in nuts grown in warm than in temperate climates. It is a non-drying, edible oil, liquid at ordinary temperatures, golden-yellow in colour, and with a pleasant nutty taste and odour. In Nigeria the oil is next only to palm oil as a culinary and edible oil, and it is also used as an illuminant.

Groundnut cake contains a higher percentage of protein than most of the other oilseed cakes. It is, moreover, highly digestible by livestock. The cake is at present produced locally in Kano, from where most of the Government and other stock farms obtain their requirements. The extraction of the oil in the Kano mills is less efficient than that in the modern pressure and solvent-extraction methods. The locally produced cake consequently contains a relatively high amount of oil (about 10 per cent.) and it is thus nutritionally less desirable than cake made overseas, since the high oil content tends to give rise to soft body-fat—a notable disadvantage of groundnut cake in livestock feeding when it is used in large quantities.

Elaeis guineensis Jacq. (oil-palm).—Nigeria is one of the most important sources of world supplies of palm kernels and palm-kernel oil, providing 381,000 tons in 1950, which was nearly half of the quantity entering the world market [12]. The relative value of the oil-palm to Nigeria's total export values has, however, declined from 23·5 per cent. in 1938 to 19·8 per cent. in 1950. The export value of palm kernels is much higher than that of palm oil, more of which is consumed within the country.

The varieties of oil-palm indigenous to West Africa tend to produce the *dura* or thick-shelled type of fruit, with relatively large kernels surrounded by a thin, fleshy mesocarp from which the palm oil is extracted. In contrast are the *tenera* varieties, the fruits of which are characterized by a thick oil-containing mesocarp inside which is embedded a small nut.

According to the current regulations in Nigeria, exported palm kernels should have a moisture content of between 7 and 9 per cent. and an average oil content of 49 per cent., with a free-fatty-acid value not exceeding 4 per cent., when they arrive in the United Kingdom. The oil from the kernels is then extracted, leaving the residual cake which is widely utilized as a concentrate for various classes of livestock.

Palm-kernel oil is a whitish-yellow fat, which resembles coconut oil in taste and odour although it is less pungent. It is easily hydrolysed and thus tends to go rancid rapidly. In Nigeria it is used occasionally for cooking, more often as a hair oil, sometimes for medicinal purposes, and in certain parts for soap making.

Palm-kernel cake, the residue after extracting the oil, contains a much smaller quantity of protein than either groundnut or decorticated cotton-seed cake, and is less palatable than these. It is, however, much used for dairy and fattening cattle, for pigs, and for horses. Animals do not take readily to the cake because of its grittiness and dryness, which causes considerable salivation during mastication, particularly in horses. It should therefore be introduced gradually and in small quantities into

the rations. Unlike groundnut cake, palm-kernel cake tends to produce a butter-fat of firm consistency and a hard body-fat.

The sample of palm-kernel cake analysed was somewhat rich in oil because of incomplete extraction, and it thus possessed more energy value than similar products produced by the modern pressure and solvent-extraction methods. Since the oil is more saturated than that of the groundnut, this somewhat high oil content would not appear to have the undesirable effect of that in groundnut cake, on the type of butter- or body-fat produced.

Phaseolus aureus, Linn. (green gram).—Green gram was recently introduced from south-east Asia, into the crop rotation of the University College, Ibadan, Agricultural Farm. Yields of up to 600 lb. of shelled grains per acre have been obtained. *Phaseolus aureus* grows to a height of about 2 ft., and spreads rapidly. The thin, hairy stems possess glabrous, trifoliate, smooth, and heart-shaped leaves.

Green-gram seed is widely used for human food in India and in the islands of south-east Asia, where it forms a valuable source of vegetable protein. The sample analysed was higher in protein than were cow-peas. It strongly resembled Lima beans in its nutrient content. Unlike the Lima bean, green gram is free from cyanogenetic glycoside, and it is a crop of promise if it can be cultivated successfully in Nigeria. In common with other pulses, green gram is a rich source of thiamine and riboflavin. The seeds were used by Eijkman in his famous experiment of 1897, in which he showed that birds fed solely on polished rice developed polyneuritis, the counterpart of beri-beri in man, which was rapidly cured when the seeds of green gram were used as a source of thiamine.

Phaseolus lunatus, Linn. (Lima bean).—The Lima bean, also known as Rangoon bean, Madagascar bean, or butter bean, is widely grown in Nigeria, particularly in the south. Here the shelled beans are commonly used in bean soups or made into one of the many edible bean products.

The composition of *Phaseolus lunatus* is generally similar to that of *P. aureus*, except that it contains hydrocyanic acid which makes it unsafe to feed raw. For this reason the seed should be well boiled, the water from the first cooking being discarded before the second cooking.

Mucuna spp. Adams (velvet bean).—Mucuna or velvet bean is a climbing herb, with compound, trifoliate leaves, which forms a rapid cover. For this reason it is most commonly used as a cover crop, and, if dug in green, it provides a valuable green manure. The pods are covered with dark brown, velvety hairs. The seeds may be black, mottled, or white.

The shelled seeds were rich in protein, low in oil, and contained a fair amount of crude fibre and mineral matter. They were high in total digestible nutrients. It has been suggested that the seeds are suitable for pigs, cattle, sheep, goats, and poultry [17]; they are more economically fed to livestock with the pods.

Cajanus cajan Druce (pigeon pea. Also known as Congo pea, red gram, or non-eye pea).—The pigeon pea is perhaps one of the most widely grown agricultural legumes in tropical and sub-tropical countries, although it is much less popular in Nigeria than elsewhere. The plant

is an erect, short-lived, perennial shrub, attaining a height of between 6 and 14 ft. The yellow or yellow-and-red flowers give rise to short and flat pods, which contain from three to five seeds. The plant is deep-rooted, widely adaptable, and drought-resisting.

Cajanus cajan is a valuable soil improver. In addition to its deep roots and its fertilizer value as a legume, its prolific growth smothers weeds and checks soil erosion. The continual leaf fall considerably enriches the soil with organic matter.

The pod, seeds, and leaves of pigeon pea form excellent fodder for cattle, sheep, goats, and horses, and these animals can be folded on the unharvested crop. The ground seeds can be incorporated as a source of protein in poultry rations.

The two varieties analysed were similar in almost all their nutrient contents, except that the indigenous variety (*ex* Ibadan) was somewhat more fibrous and oily than the exotic type (*ex* Trinidad), which seemed to be slightly better in all other respects. Both samples were grown on the same soil at Moor Plantation, Ibadan.

Glycine soja Merr. (soya-bean).—The soya-bean is, perhaps, one of the oldest crops in cultivation, the first record of the plant in China being attributed to 2838 B.C. Soya-bean has not yet been established in Nigeria or in any other part of West Africa, where its cultivation in native agriculture is unknown. Climatically West Africa would appear suitable for soya-bean production, and the importance of the crop in commerce as well as its high nutritive value seem sufficiently great to justify a determined attempt to establish it.

Soya-bean is cultivated principally for its oil-bearing seeds, which are widely used for human consumption, as a concentrate for farm animals, or for the extraction of oil, leaving soya-bean oil meal. The seeds are also employed in the manufacture of other edible and industrial products, and the plant is used as a forage crop.

The analysis reported in this paper shows that soya-bean grown in Nigeria was fairly rich in protein, good in oil content, and had average amounts of fibre and ash. The composition of the crop agreed well with the analyses of soya-beans grown in the United States of America, as reported by Bailey *et al.* [18] and by Carter *et al.* [19]. Great variations occur in the chemical constituents of soya-beans. In a study of 128 varieties prepared by the United States Department of Agriculture [20] the protein content varied from 32·4 to 50·2 per cent., and the oil from 13·9 to 23·2 per cent. Soya-beans with a low oil content were high in protein and vice versa.

The biological value of the proteins of soya-bean oil meal or cake is fairly high. Csonka and Jones [21] found that soya-bean is rich in lysine and tryptophane, and it contains all the known nutritionally-essential amino acids. Soya-bean and soya-bean oil meal therefore provide feed of high nutritive value for all classes of farm livestock.

Citrullus vulgaris Schrad. (water-melon. Yoruba, *egunsi*; Ibo, *ogili*; Hausa, *agusi*).—The water-melon is a creeping annual that belongs to the Cucurbitaceae (gourd family). It possesses hairy stems, deeply divided and triangular-shaped leaves, and small, yellow flowers. It is

sown in rotation with maize and other crops in Nigerian agriculture, where it is widely cultivated.

The large, circular fruit is made up of white fleshy material inside which are embedded small flat seeds. While the water-melon is cultivated abroad principally as an edible fruit, it is grown in Nigeria mainly for its seeds, which form one of the most common sources of vegetable protein. There are two main varieties used for this purpose, namely, 'Bara' and 'Serewe'.

It was found (Table 1) that the seeds of water-melon, when shelled, were rich in protein (34 per cent.) and in oil (57 per cent.). They were an even richer source of these two constituents than some of the more popularly known oil-seed and leguminous crops. The oil is a semi-drying one, which has been reported to be as valuable as cotton-seed oil [6, p. 219].

Of the two varieties analysed, the 'Bara' variety seemed consistently richer in protein, ash, and fibre, but poorer in oils and soluble carbohydrates than the 'Serewe' variety, which has a thinner and somewhat flatter seed than the former.

Summary

The chemical composition and the calculated nutritive value of the cereal and protein concentrate feedingstuffs grown in Nigeria have been examined.

It was found that maize, Guinea corn (sorghum), and paddy rice were better sources of nutrients than bulrush millet (*Pennisetum typhoideum*). Acha grain (*Digitaria exilis*) was markedly inferior to all the other cereal grains examined. These locally grown cereal concentrates tended, in general, to be low in oil and fibre, somewhat high in carbohydrates and total digestible nutrients, and average in protein and mineral matter.

The high nutritive value of the protein concentrates: water-melon seed (*Citrullus vulgaris*), African locust bean (*Parkia filicoidea*), and Bambara groundnut (*Voandzeia subterranea*), which are peculiar to and are of widespread use in the country, was demonstrated. The locally grown oilseed crops tended to be somewhat low in protein, high in oil and fibre, and average in mineral matter.

In general, however, the locally grown concentrate feedingstuffs when compared, on a qualitative rather than a yield basis with those grown abroad, gave only small differences in their content of protein and minerals. Allowing for adequate breeding and selection of seeds, then, in protein, mineral, oil, carbohydrate, and total digestible nutrient contents, the cereal and protein concentrates grown in Nigeria are quite similar to those used elsewhere.

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(Received 4 May 1955)

THE CATTLE OF THE FUNG: A LOCAL VARIANT OF THE SHORT-HORNED ZEBU, INDIGENOUS TO THE NORTHERN SUDAN

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With Plates 5–7

THE Fung is that part of the north-central Sudan which lies between the White and Blue Niles, and is bounded on the north by the Sennar–Kosti railway at approximately 13° 30′ N. and on the south by the Machar Marshes at approximately 9° 30′ N. It is a flat clay plain lying within the low-rainfall woodland-grass savannah belt which extends across Africa south of the Sahara. The dominant grasses in the Fung are tall annuals (e.g., in order of their rainfall requirement, *Cymbopogon nervatus* Chiov., *Sorghum purpureo-sericum* Aschers & Schweinf., and *Hyparrhenia pseudocymbaria* Stend., together with species of more local distribution but greater palatability, such as *Brachiaria obtusiflora* Stapf.), which occur in open grassland or in scattered or thick woodland dominated by *Acacia mellifera* Benth., *Acacia seyal* Del., and *Acacia fistula* Schweinf. [1, 2, 3].

The climate is typically that of a tropical continental area with a clearly defined rainy season. Precipitation is distributed over the period May to October, with the greater part concentrated in June to September. Annual rainfall increases from the north (about 18 in.) to the south (about 32 in.) of the area. Temperatures are generally similar to those recorded at the Gezira Research Farm (Table 1), with a tendency for the range to be progressively more restricted towards the south [3].

Two semi-nomadic tribes, the Kenana and the Rufa'a el Hoi, graze their cattle over the greater part of the Fung. A third tribe, the Rufa'a el Sheriq, have their grazing grounds to the east of the Blue Nile and spend the dry season near the river Dinder. The cattle of these tribes, which have been estimated from the numbers brought forward for vaccination against cattle plague to be at least 60,000 and probably more nearly 80,000 head (J. K. Thompson, personal communication), are a local variant of the short-horned zebu which occurs throughout this vegetational belt in the northern Sudan. The cattle are commonly referred to by the name 'Kenana' [4, 5, 6] or 'Rufa'ai'. Other local variants which have been described elsewhere are the red cattle of the Butana [7], the cattle from the west bank of the White Nile [6], and those of the riverain lands to the north of Khartoum [6]. Cattle which appear from the published descriptions to be of this type (the Maure, Tuareg, Shuwa, and Azaouak zebus) occur in the territories to the west of the Sudan and have been described by Doutressoulle [8] and Mason [9]. The close resemblance between the conformation and performance of these cattle and those of some Indian and Pakistani types [10] makes it appear reasonable to

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

assume that they are derived from immigrant stocks which had their origin in southern Asia [11].

The nature of the native environment of the cattle is largely determined by the seasonally limited rainfall, which results in an alternation between conditions during and following the rains (June to November), when grazing and water are abundant, and those in the dry season and early rains (December to May), when the cattle subsist mainly on dry grass residues and may have to go two days between waterings. In a normal year, however, it is only in April and May that severe nutritional deficiency is evident.

Each year the herds migrate from south to north at the beginning of the rains and return as they end. The northward movement, which entails a walk of 250 to 300 miles, is occasioned primarily by the necessity for removing the cattle from the swarms of biting flies (Tabanids and *Stomoxys* spp.) which emerge in the rains [12].

Cattle are maintained for their milk, and in the Gezira as work animals. An attempt is made to breed for milk, bulls being selected on the basis of their dams' performance. Beef is seldom eaten by the pastoralists (large flocks of sheep are kept for the supply of the more highly esteemed mutton), and no effort is made to select cattle of superior meat conformation.

The Gezira Research Farm Herd

A herd of 164 cattle, of which 39 were mature females, was maintained at the Gezira Research Farm, as at 31 December 1954. Hattersley [5] has given an account of the early history of this herd and of its management up to the end of 1950. The herd was derived from eleven individuals, all of which except one (an animal of similar type obtained near Wad Medani) were purchased in the Fung. In the account which follows, data derived from the records of this herd will be used to describe the cattle type.

Situation, soil, and climate of the Gezira Research Farm.—The Gezira Research Farm is situated 3 miles west-south-west of Wad Medani, in lat. 14° 24′ N., long. 33° 29′ E., within the irrigated area of the Gezira which forms part of the same clay plain as the Fung some 60 miles to the south. The elevation above sea level is 1,335 ft.

The soil is similar in origin, appearance, and content to much of the clay soil of the Fung. It is dark in colour, heavy (containing 50–60 per cent. of clay through the top 6 ft.), and alkaline (with a pH of about 9·0). It contains about 0·2 per cent. of soluble salts, mainly sodium carbonate in the top 2 ft. and sodium sulphate in the second 2 ft., with gypsum in the subsoil, and is highly impermeable [13].

The climate is similar to that of the Fung, but, owing to the more northerly situation, precipitation is less and is distributed over a shorter period. Temperatures in the winter tend to be cooler and in the summer hotter than in the Fung. Climatological data for the Gezira Research Farm are presented in Table 1.

The feeding of the herd.—The feeding of the herd has been based on irrigated crops, the nutritive status of the cattle being maintained at a

constant level throughout the year. Almost all the feed was obtained from two crops: *Dolichos lablab* L., which was grazed under close-folding conditions as well as being fed to the cattle in the yards as hay, and *Sorghum vulgare* Pers., the straw of which was fed in the yards while the grain, together with locally produced oil-seed cake (cotton seed, groundnut, and sesame), provided a concentrate ration for the cows in milk, breeding and draught bulls, and growing stock. Calves were pail-fed and received about 60 gallons of milk a head.

The health of the herd.—Since 1947 when a number of cattle died of cattle plague, and 1948 when foot and mouth disease appeared in the herd, there has been little serious illness. All the cattle were vaccinated against cattle plague, haemorrhagic septicaemia, and anthrax. As there was no contact with other cattle it was not thought necessary to immunize the cattle against contagious bovine pleuro-pneumonia.

TABLE 1. *Climatological Data for the Gezira Research Farm*

Month	*Mean maximum temperature °F.*	*Mean minimum temperature °F.*	*Mean relative humidity at 0600 hrs.*	*Rainfall in.*
			%	
Jan.	93·2	57·4	36	0
Feb.	95·5	58·6	26	0
Mar.	101·3	63·9	19	0
Apr.	106·0	70·0	18	0·12
May	106·0	74·7	29	0·59
June	103·3	76·3	46	1·30
July	96·3	73·0	66	4·72
Aug.	92·3	71·6	77	5·04
Sept.	96·3	71·4	70	2·16
Oct.	100·9	71·2	51	0·59
Nov.	98·1	64·6	35	0·04
Dec.	93·7	59·2	38	0
Total	..	..	..	14·57

Source: Sudan Meteorological Service; averages for 30 years.

In late 1953 and early 1954 a tuberculin test was carried out on the herd. The non-specific reaction was demonstrated but the presence of the mammalian strain of the organism was not established and none of the cattle had to be discarded. Earlier in 1953 a herd test for *Brucella melitensis* was uniformly negative in result.

Streptococcal mastitis appeared at intervals in the herd and an attempt was made to eliminate it by prophylactic treatment with penicillin. A few cases of hoven occurred when animals were grazing young leguminous crops. No cases of infectious infertility have yet been diagnosed in the herd.

The breeding of the herd.—The present herd is descended from eight cows and three bulls, none of which was introduced later than 1941 except one bull which was purchased in 1944 and which at the time of writing was represented in the herd by five descendants.

As a result of the extensive use of one bull between 1942 and 1951, the level of inbreeding of calves born into the herd rose in 1951 and 1952. The mean coefficient of inbreeding according to Wright's formula [14] was 6·9 per cent. for the 9 calves born in 1950. Its value for the 10 calves born in 1951 and the 28 calves born in 1952 was 14·4 and 12·7 per cent. respectively. A daughter–dam comparison indicated that the bull was not raising its daughters' productive ability as compared to that of their dams and it was discarded (averages of 19 daughter–dam pairs: dams, 3,879 lb. milk; daughters, 3,822 lb. milk). After the bull had been discarded the level of inbreeding of calves fell; the means for the coefficient of inbreeding for the 1953 and 1954 calf crops were 7·7 per cent. (30 calves) and 4·6 per cent. (39 calves) respectively. Four bulls are now being used concurrently, each on cows which are not closely related to it.

In the past two years the aim of selection has been transferred from a work-milk animal, suitable for the non-intensive management of the Gezira cultivator, to one which would be able to convert irrigated fodder crops into milk with an efficiency sufficiently high to enable the product to be sold cheaply in the towns and villages. Docility, constitution, and working ability in the male were necessary subsidiary qualifications. Individuals which showed the unusual beefy conformation were being retained in the herd even if they were poor milk producers. In the past there had been considerable emphasis on selection for uniformity of coat coloration, and it had been possible for a high-yielding cow to be culled on that score. Recently, atypical coat coloration was no longer considered to be sufficiently important to merit the disposal of an animal unless it was also a poor producer.

The only anomalies of a genetic origin which have been observed have been variations in horn development, discussed below, and deformations of the lower jaw. Slight prognathia is common among cattle in the Fung and at the Gezira Research Farm. (The absence of short grazing in the pastoral environment would tend to minimize natural selection against this character.) One case of brachygnathia has been observed in a male animal at the Gezira Research Farm.

There have been occasional references in the back records of the herd to calves which were 'mis-shapen' at birth and were destroyed, but there have been no descriptions of the deformations. More recently a hydrocephalic calf (coefficient of inbreeding, F = 18·75 per cent.) was born prematurely by a heifer.

The conformation of the cattle.—The distinguishing features of the Fung type of cattle are given below:

(*a*) The head is long and coffin-shaped, with the greatest width above the level of the eyes. The face is thin, and the profile is convex, or, more rarely, straight in the female, and convex, straight, or slightly concave in the male. The distance from the poll to the eyes is about half that between the eyes and the muzzle. The orbital arches are not prominent, but, in the bull, the forehead is massive and may tend to overshadow the eyes. The ears are of medium size (about $5\frac{1}{2} \times 9$ in.) and are usually carried approximately horizontally (Plates 6 and 7, Figs. 4–9).

(*b*) The horns are a broad oval in cross-section, about 2 in. $\times 2\frac{1}{2}$ in.

at the base in the female and 2½ in. × 3 in. in the male. The horns grow from a flat poll outwards and upwards, approximately in line with the line of the profile, and turn inwards and forwards at the tips. The horns do not usually exceed 12–14 in. in length (Plate 6, Figs. 4, 5). Modifications in the development of the horns occur. Except that the true polled phenotype has not been observed in these cattle, the modifications in horn growth appear to be very similar to those described by Williams and Williams [15] as occurring in polled Hereford cattle. The modifications in horn development are: (1) short mutilated horns, either attached or loose (Plate 7, Fig. 6); (2) unattached horns of normal length hanging downwards by the cheeks (Plate 7, Fig. 7); (3) scurs which can be either in the form of a short stub which may be attached or loose, or a flat scur which is not attached to the skull (Plate 7, Figs. 8, 9).

A peaked poll is normal with scurs or loose horns (Plate 7, Figs. 7, 9), but scurs have also been seen on a round poll (Plate 7, Fig. 8). Only normal horns or loose horns of normal length have been observed in the male.

(*c*) The hump is muscular, and cervico-thoracic in position. In the female and the castrate male it is small and often of nearly equal slope from front and rear (Plate 5, Fig. 2). In the male it is larger—about 4–8 in. high from the withers—and its tendency to overhang to the rear makes it appear to be more nearly thoracic in position (Plate 5, Fig. 1).

(*d*) The dewlap and umbilical fold are well developed (Plate 5, Figs. 1, 2). The dewlap is loose and folded in both sexes. Its average depth is 10½ in. in the female (18 samples) and 12½ in. in the male (16 samples). It starts under the chin, often as a double fold, and ends at the breastbone between the forelegs. In extreme cases it may be continuous with the umbilical fold. The average depth of the umbilical fold in the female is 3½ in. (19 samples), and in the male the average depth of the sheath is 5½ in. (16 samples).

(*e*) The pelvis is short, and narrow posteriorly. The prominence of the sacrum accentuates the steep slope of the pelvis from front to rear, which is a contributory cause of the upright position of the hind legs. A tendency towards 'cow-hocks' and a poor udder attachment is in large part due to the posterior narrowness of the pelvis. The tail setting is low, and the tail is long with the switch normally reaching to the fetlock.

(*f*) The general conformation of the cattle is characterized by a lightness of bone and leanness of musculature. There is a tendency for the ribs to be flat, and for the back and hindquarters to be ridged. These tendencies can be corrected to some extent by rearing the animal to maturity with both adequate and stable nutrition, and they are much less in evidence in the Gezira Research Farm herd than among the pastoral herds, where the effect of seasonal fluctuation in the availability of feed is apparent.

(*g*) Coat coloration: the skin (about 4 mm. thick on the side of the neck in the mature female and 6 mm. in the mature male) is pigmented black or brown, with the exception of the inside of the ear, the udder and teats,

and, to some extent, the belly, which are of a yellowish colour. The horns, hooves, muzzle, tongue, surround of the eye, and switch are black. The coat is short and close, with hairs about ¼–½ in. long. The hairs are banded black near the root, while the extremities are red or white. The degree of extension of the black band determines the tone of the coat colour. The shade of the coat colour depends on the colour of the hair tips, and a range between full red and full white is possible. Variation in the extent of the black banding results in the appearance of

TABLE 2. *Average Measurements of Cattle at the Gezira Research Farm*

Age in months	*No. sampled*	*Measurements in inches Mean ± SE.*				
		Height at withers	*Depth of chest*	*Length from shoulder point to pin bone*	*Heart girth*	*Width of hips*
MALES						
9–12	2	44·3 ± 0·2	20·7 ± 0·2	41·7 ± 0·4	50·0 ± 1·2	11·0 ± 0·4
13–18	7	46·4 ± 0·9	22·8 ± 0·7	46·7 ± 1·2	51·9 ± 1·3	12·6 ± 0·4
19–30	8	49·4 ± 0·8	24·9 ± 0·5	51·6 ± 0·7	59·4 ± 0·8	14·5 ± 0·4
31–42	10	50·9 ± 0·6	26·1 ± 0·4	53·5 ± 0·5	62·0 ± 0·8	15·3 ± 0·4
43–54	4	53·5 ± 0·7	27·7 ± 0·6	56·4 ± 0·5	67·6 ± 1·7	16·5 ± 0·4
55–	17	55·6 ± 0·3	31·2 ± 0·3	62·4 ± 0·7	73·2 ± 0·8	18·4 ± 0·3
FEMALES						
9–12	7	40·7 ± 0·4	17·9 ± 0·4	41·4 ± 0·7	46·1 ± 1·6	11·0 ± 0·4
13–18	14	44·4 ± 0·4	20·4 ± 0·4	45·9 ± 0·7	51·6 ± 0·5	13·0 ± 0·3
19–30	5	46·2 ± 0·9	22·0 ± 0·6	49·2 ± 0·4	56·3 ± 0·7	14·5 ± 0·4
31–42	15	48·0 ± 0·4	24·1 ± 0·5	50·4 ± 0·5	60·4 ± 0·7	15·6 ± 0·4
43–54	9	50·3 ± 0·6	26·7 ± 0·3	53·6 ± 1·0	66·5 ± 0·9	18·0 ± 0·6
55–	28	51·2 ± 0·3	27·4 ± 0·4	55·4 ± 0·6	67·0 ± 0·7	18·7 ± 0·3

dark areas superimposed on the basal colour. In the lighter-coloured animals these dark areas are confined to the front of the knee and the fetlock and coronet, but in those of darker coloration they are distributed over the head and shoulders, the hindquarters and topline, the knee and front edge of the foreleg, and the lower part of the hindleg.

In the calf the extremities of the hairs are red over an area of the body which can vary from the whole surface to the poll alone. The red poll has been present in all white calves that have been observed. White hair tips in the calf are associated with the minimum extent of the black banding. (Of the four bulls now being used at the Gezira Research Farm, one—the darkest—has sired only red calves, while the remaining three have sired red calves and white calves with a red poll in approximately equal numbers. Red calves appear to be normal in pastoral herds.) The red colour normally disappears before the calf is 6 months old, leaving the hair tips white and resulting in the characteristic grey coloration of the cattle of the area. Exceptionally the red colour may remain, and a few animals continue to appear in the Gezira Research

Farm herd in which the red coloration persists in some degree to maturity in spite of fifteen years of selection against it.

A few females have emerged in the herd which are shorter and heavier in the leg, deeper in the body, and broader in the back than the generality of the type. The conformation of these individuals suggests that the development of a beef type by selection among the northern Sudanese cattle might not be impossible (Plate 6, Fig. 3).

Measurements and live weights obtained at the Gezira Research farm for cattle at different stages of growth are presented in Tables 2 and 3.

TABLE 3. *Average Live Weights of Cattle at the Gezira Research Farm*

	Live Weights in pounds			
	Males		*Females*	
Age in months	*Number sampled*	*Mean ± SE.*	*Number sampled*	*Mean ± SE.*
Birth	73	52·4 ± 0·9	84	48·6 ± 0·7
6	57	230·3 ± 6·2	64	214·3 ± 4·4
9–12	2	332·9 ± 11·0	7	311·8 ± 15·8
13–18	7	449·7 ± 28·4	14	401·8 ± 13·2
19–30	8	604·1 ± 21·7	5	528·8 ± 21·0
31–42	10	686·5 ± 24·2	15	640·5 ± 24·2
43–54	4	891·2 ± 70·9	9	842·5 ± 31·5
>54	17	1163·9 ± 31·6	28	883·9 ± 19·0

The temperament of the cattle.—As a result of the rigorous culling of all animals which show themselves to be incorrigibly wild, and of the constant presence of the herdsmen and other members of the farm staff to whom they are accustomed from calfhood, the cattle are docile and easily handled. A sudden alarm, however, may awaken their native excitability and agility, and make their restraint difficult.

The bulls are easily trained and quickly become accustomed to draught work.

The climatic adaptability of the cattle.—The cattle are able to tolerate high air temperatures. Table 4 contains material derived from observations on six groups of cattle which were exposed to direct sunlight in an unshaded yard with unprotected soil underfoot. Feed and water were provided in the yard. The first test (that on ten mature cows) was carried out in March, 1954, and the others were completed in October, 1954. Each group of cattle was confined in the yard from 0700 hrs. to 1600 hrs. on two separate days. Rectal temperatures were taken at 0700 hrs. and at 1545 hrs. Throughout the tests the sky was clear and air movement varied from a complete calm to a gentle breeze (strengths 0–3 on the Beaufort scale). The average air shade temperature at 0800 hrs. on the days of the tests was 81·8° F. and the average maximum shade temperature reached during the exposure periods was 100·9° F. The average relative humidity at 0800 hrs. on the days of the tests was 47·8 per cent.

Using Rhoad's formula [16] (Adaptability coefficient,

$$A = 100 - 10(BT - 101{\cdot}0),$$

where BT is the mean of all recordings of body temperature during the test, and 101·0 is the normal body temperature of cattle) an average adaptability coefficient of 89·2 was obtained for all cattle tested. The mean body temperatures of all the cattle before and after exposure were 101·5° F. and 102·7° F. respectively.

A fall in air temperature results in signs of distress in the cattle, and on cool winter mornings when air temperatures may fall below 50°F. they stand huddled together, with staring coats, and milk production falls appreciably.

TABLE 4. *Climatic Adaptability of Cattle at the Gezira Research Farm*

Class	*No. of cattle in test*	*Av. body temp.*		*Adaptability co-efficient A*	*Mean air shade temp. during test*		*Mean rel. humidity for test at 0800 hrs.*
		Before exposure °F	*After exposure °F*		*0800 hrs. °F*	*Max. temp. °F*	
							%
Mature cows .	10	101·1	101·8	95·0	79·8	104·7	33·0
Mature cows .	5	101·4	102·3	92·0	82·0	99·2	54·5
Heifers: av. age 34·3 mths. .	6	102·0	103·0	85·0	82·6	99·0	55·0
Heifers: av. age 10 mths. .	6	102·1	103·4	83·0	82·6	99·0	55·0
Mature bulls .	6	101·5	103·2	87·0	82·2	103·1	34·5
Bulls: av. age 28·2 mths. .	6	101·1	103·0	89·5	81·7	100·6	55·0

Breeding performance.—The information given below is derived from the records of cows which were in the herd at the time of writing or had been disposed of during the past two years.

The average age of a cow at its first calf was $40{\cdot}6 \pm 0{\cdot}8$ (41) months (mean ± standard error, with number of observations), with a range of 27·0–53·5 months. Bulls could be used for service from about 24 months of age.

In general there was no difficulty in observing heats in the cows. As it was possible, however, that the late age at first calving might have been due, at least in part, to a failure to observe heats in the heifers, a young bull has been run with them since 1952. As there has been no reduction in the age at which heifers calve down for the first time it must be concluded that, in this herd, heifers do not arrive at sexual maturity until they are over 2 years of age.

Heats occurred regularly throughout the year, and no tendency towards a breeding season has been observed. (In the pastoral environment, although calves are produced throughout the year, there is a tendency towards an environmentally imposed breeding season and most

calves are born in the middle and late rains, in July to October.) There has been no detailed observation of the duration of the heat period, but it has been estimated as being generally about 6 hours, with a range of from less than 1 hour to 12 hours or more.

After calving down for the first time, cows were not run with a bull, but, as they came on heat, they were brought to selected bulls for service. A pregnancy diagnosis per rectum was performed 8 weeks after a cow had been served, and in cases of temporary sterility the appropriate treatment was given.

The average calving interval during the 7 years 1948–54 was 408±9 (115) days.

TABLE 5. *Lactation Yields and Days in Milk: 1948–54**

Year	Number of lactations	Milk production in lb.†		Days in milk‡	
		Mean±SE.	Range	Mean±SE.	Range
1948	14	3,318±278	1,606–4,840	224± 9	154–278
1949	21	3,632±269	522–6,303	251±16	58–424
1950	22	3,875±296	672–6,514	232±15	62–367
1951	23	3,677±318	324–6,676	229±14	68–342
1952	26	3,856±276	262–6,165	223±13	58–348
1953	15	3,965±212	2,196–5,143	275±16	152–358
1954	28	4,045±271	902–6,108	260±11	151–414

* The values are for normal lactations (uninterrupted by disease or other cause) ending in each year.

† Milk yields were recorded from the fourth day after calving.

‡ Days in milk were measured from date of calving to date of drying off.

The 121 calves produced by cows which were in the herd at the time of writing required 173 services: 1·4 services to a calf.

No twin births have been recorded in the herd.

Of the 317 calves which have been recorded as having been born to past or present herd members, 51·1 per cent. were males and 48·9 per cent. were females.

The average gestation period was 286·6±0·6 (126) days. The difference between the gestation period for male calves—287·8±0·8 (54) days—and that for female calves—285·6±0·8 (72) days—was not significant.

Milk production.—Milking has been by machine, carried out twice daily at 12-hourly intervals. For the first 4 weeks after calving, cows are milked three times daily so that the calves can have a midday feed of fresh milk. Calves suckled their dams until 1948. In 1948 suckling was stopped, but the calves remained in the milking shed tethered by the cows' heads. At the present time, a heifer's first calf is removed at birth and she is trained to be milked in its absence. Milk yields are weighed and recorded at each milking.

The lactation records for the years 1948–51 have shown that the mean milk yield was 3,795±111 (149) lb. milk and the mean duration of a lactation was 242±5 (149) days. The highest and lowest lactation yields

recorded were 6,676 lb. in 342 days and 262 lb. in 58 days respectively. The mean dry period was 182±11 (130) days.

Ten superior cows, all of which were in the herd at the time of writing, had an average yield of 4,908±188 (30) lb. milk in 282±8 (30) days.

Mean yields and days in milk for lactations ending in the years 1948–54 are presented in Table 5.

A study of 102 lactation records for cows in the herd in December 1954 indicated that a cow was most likely to attain its highest yield in its third lactation. The results of this study are shown in Table 6.

In an attempt to define the interdependence of successive lactations of the same cow it was found that the relationship between the heifer lactation and the second lactation ($r = +0{\cdot}4545$; 17 degrees of freedom;

TABLE 6. *Milk Yields and Days in Milk in Successive Lactations*

Lactation	*Number of lactations*	*Milk production in lb.**		*Days in milk†*	
		Mean±SE.	*Range*	*Mean±SE.*	*Range*
1	24	3,707±267	1,462–6,240	256±15	131–367
2	24	4,150±217	2,174–6,426	266±11	152–358
3	17	4,330±260	2,746–6,744	250± 8	190–342
4	12	4,073±270	2,676–6,096	232±10	167–280
5	8	3,951±148	3,512–4,601	258±13	213–327
6 or over	17	4,142±200	2,370–5,822	264±11	211–346

* Recorded from the fourth day after calving.
† Measured from the date of calving to the date of drying off.

on the verge of significance) was less pronounced than either that between the second and third lactations ($r = +0{\cdot}6367$; 14 D.F.; highly significant) or that between the third and fourth lactations ($r = +0{\cdot}7115$; 9 D.F.; significant).

An average interval of 18±4 (94) days occurred between calving and the attainment of the mean peak daily yield of 27·8±1·8 (94) lb. milk.

The shape of the lactation curve can vary considerably. In lactations made by the poorer producers the maximum daily yield was normally attained in the first week of lactation, after which production fell rapidly until the lactation was terminated. With superior cows the attainment of the daily maximum was delayed until several weeks after calving, and the subsequent decrease was at a lesser rate until the lactation was about to end, when it fell sharply. The heifer lactation often presented a lower, flatter, and more prolonged curve than subsequent lactations.

In a further examination of the material the correlation between lactation duration and total yield was found to be very strongly marked. The correlation coefficient for the relation between days in milk and total yield was $r = +0{\cdot}7609$, with 77 D.F. (highly significant). The correlation between initial high yield and total yield, although also highly significant ($r = +0{\cdot}4367$ with 73 D.F.), was less striking. The month in which calving occurred had no significant effect on total yield or on the duration of lactation.

The average herd life of the 31 cows which are recorded as having been disposed of from the herd was 6·3 lactations. Included in these 31 cows were 14 home-bred cows which completed their whole productive lives in the herd with an average herd life of 11 lactations. The highest number of lactations in a lifetime was 15.

The composition of the milk.—The average values of milk analyses carried out over 15 years are given in Table 7.

Work performance.—Much of the haulage and tillage work at the Gezira Research Farm, especially on experimental plots, is carried out by bulls. All male cattle are trained for this work from about 2 years of age. At the time of writing there were 35 bulls working or in training (including four which were not bred on the farm).

A pair of bulls performing tillage operations is capable of working a 5–6 hour day. During this time two-thirds of a feddan (0·7 acres) can

TABLE 7. *Composition of Milk from the Gezira Research Farm Herd (Averages of 15 years)*

Constituent	*Number of tests*	*Value Mean ± SE.*	*Range*
Butterfat, per cent. . . .	234	4·73 ±0·09	1·2 –10·6
Solids-not-fat, per cent. . .	234	9·25 ±0·04	5·1 –10·4
Total solids, per cent. . .	216	13·17 ±0·11	8·6 –18·2
Specific gravity . . .	174	1·0304±0·0004	1·021– 1·036

be ploughed or 2½ feddans (2·6 acres) ridged up. Hattersley [5] has observed that a pair of bulls will walk 9–10 miles in a 5-hour day while engaged on ridging.

When used for haulage a pair of bulls can work a 7-hour day. Two bulls harnessed to a flat trolley with four iron-tyred wheels can move a load of 1·1 tons over rough earth roads.

The bulls are harnessed to implements and vehicles in pairs by the 'Walley' yolk [17], a straight beam which lies across the animals' necks and is fastened directly to the drawbar.

Discussion

The work which has been done on the Gezira Research Farm herd gives an indication of the producing ability of the Fung type of cattle in an improved environment. The eight foundation cows were selected from about one hundred animals that were purchased in the Fung in 1940 or 1941, or (a limited number) a few years previously. Unfortunately the records prior to 1948 were incomplete and it is difficult properly to assess the superiority of the selected animals over the remainder. At about this time, also, an attempt to obtain uniformity of coat coloration appears to have diverted attention from more economically useful qualities, and valuable material may have been discarded on this score. For example, a cow which had been rejected from Gezira Research Farm herd was taken by the School of Agriculture at Shambat,

and later, under special management and feeding, gave 10,272 lb. of milk in 339 days [6], a yield which is probably the highest recorded from an indigenous African cow.

A further indication of the productive capacity of this type of cattle is found in the records of the herd maintained at Shambat by the Faculty of Agriculture, University College of Khartoum. This herd, the establishment of which as a military dairy in 1940 has been described by Boyns [6], has had a continuity of informed management from its foundation, and selection has been directed towards the development of an economically useful dairy cow. The present herd, containing rather more than forty mature females, derives from 223 foundation cows which were purchased in 1940. These cattle (all of northern Sudan type) were obtained from a wide area; some from the Fung, others from the west bank of the White Nile near Kosti, and others from the riverain lands to the north of Khartoum. The average lactation yields in 1952 and 1953 were 4,768 lb. of milk in 309 days (33 records) and 4,647 lb. of milk in 328 days (38 records) respectively, with maxima at 7,519 lb. in 346 days and 7,247 lb. in 335 days.

When it is remembered that these records and those of the Gezira Research Farm herd were obtained after no more than 15 effective years of selection from the indigenous material, it becomes evident that the productive ability of the northern Sudan zebu compares very favourably with that of types of milch cattle native to the Indian sub-continent [10], and exceeds by a considerable margin that of any other African type [18].

It would appear, then, that a herd average of 4,000 lb. or possibly 5,000 lb. of milk (with maxima in the range 6,000–8,000 lb.) is attainable after three to four generations of selection from the foundation material. An attempt to raise the production mean above this level could be expected to present increasing difficulty, and it might be necessary to introduce genetical material from types of milch cattle of greater productivity before a higher mean could be successfully attained and stabilized.

Northern Sudan zebus have been crossed with European cattle at a dairy farm close to Khartoum, and in a few isolated instances elsewhere. The imported bulls have not survived for any length of time, but their progeny seem to have been reasonably successful. The milch cattle at the dairy farm near Khartoum are for the most part descended from Friesian bulls which were used on the native cows [19], and they have shown themselves to be capable of higher yields than the majority of indigenous cattle, while their heat tolerance and disease resistance have generally been adequate under improved dairy conditions. For town dairy purposes where a highly efficient dairy cow is required, it seems probable that further investigation into the cross-breeding of northern Sudan cattle with European milch breed would be profitable.

It has been possible to find records of only two occasions on which northern Sudan cattle have been exported. In 1941 a group of the cattle were taken to Kenya by a retiring official, and in 1949 five bulls and four heifers were sent by air to Tripolitania. In both instances the cattle

were obtained from the Gezira Research Farm and were of the grey Fung type. No detailed information is available as to the performance of the cattle in their new environments, but, at least with those exported to Tripolitania, unofficial reports have been very favourable. Cattle which were sent from the Gezira Research Farm to Juba in Equatoria Province are reported to have done less well, but again there has been no detailed account of their performance. The indications appear to be that these cattle will thrive in a hot, dry climate but may require careful treatment if temperatures are low or the humidity high for any considerable period of time.

It is very probable that there are arid and semi-arid areas in Africa and elsewhere where the efficiency of the supply of milk to population centres could be improved by the introduction of the Fung type of cattle. At the present time, however, the amount of selected material is small and is as yet insufficient for the improvement of dairy herds in the Sudan itself. The development of an export trade on any but the smallest scale must, therefore, await a further expansion of breed improvement work with this valuable but little-known type of cattle.

Summary

Observations on the herd of cattle at the Gezira Research Farm are used to describe the type of cattle indigenous to the Fung area of the north-central Sudan. These cattle are a local variant of the short-horned zebu occurring in the woodland-grass savannah belt south of the Sahara.

In conformation and performance the Fung cattle resemble types in the Indian sub-continent, and they are superior as milk producers to other indigenous African types. Live weights, measurements, breeding results, and production figures are given, the production figures for the herd of similar cattle maintained by the University College of Khartoum being mentioned for comparison. It is suggested that this cattle type could be of considerable value in improving milk production in the dry tropics.

Acknowledgements.—The writer is indebted to Mr. R. C. Maxwell-Darling, Chief, Research Division, Ministry of Agriculture, Sudan Government, who gave facilities for the work on the Gezira Research Farm herd, and to Dr. B. M. Boyns, Dean, Faculty of Agriculture, University College of Khartoum, who made available the records of the herd at Shambat.

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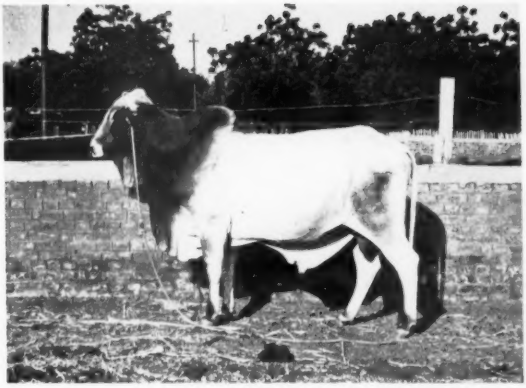

FIG. 1. A bull in the Gezira Research Farm herd

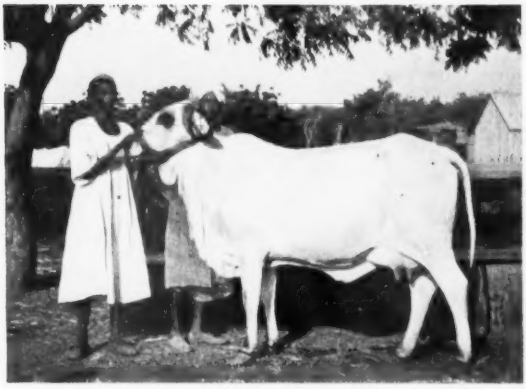

FIG. 2. A cow in the Gezira Research Farm herd

FIG. 3. A heifer of a typical 'beefy' conformation

FIG. 4. Head of a bull with normal horns

FIG. 5. Head of a cow with normal horns

FIG. 6. Head of a cow with attached 'mutilated' horns

FIG. 7. Head of a cow with unattached horns of normal length

FIG. 8. Head of a heifer with scurs and round poll

FIG. 9. Head of a heifer with scurs and peaked poll

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(*Received 28 January 1955*)

DRY-MATTER DISTRIBUTION IN THE FODDER-BEET ROOT

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THE dry-matter distribution of fodder roots has been under investigation for some considerable time. Of the earlier workers, Collins [1] showed a direct relationship between the feeding value of swedes and the total dry-matter content of roots. This he attributed to variation within the individual root, the size of root, the manures used, the soil and district where the roots were grown, the variety, and the season.

Anderson [2], working with mangels, found differences in the composition of certain varieties and within the individual root. Wood and Berry [3], again examining mangels, confirmed Collins's findings with respect to variation. They divided a number of roots into four or five horizontal slices, each being further subdivided into concentric rings. The dry-matter, sugar and nitrogen contents were then determined for each piece.

For root sampling to determine dry-matter content, Collins found that the most satisfactory estimation was obtained by taking a core that passed through the centre of the root. Wood and Berry considered that a diagonal core through the centre of the root was liable to inaccuracy owing to the rapid change in composition just below the leaf scars. With long roots the core would thus contain too much material low in dry-matter. Accordingly they took their cores horizontally, through the greater diameter of the root, where the composition varied least of all.

Nevertheless, the diagonal core was adopted as the standard method of sampling for root dry-matter estimations, and only with the introduction of fodder beet into this country has there been a renewed interest in sampling methods. Some workers have suggested that fodder beet may have a 'within-root' dry-matter distribution which would render the standard method of sampling inaccurate.

Bearing this in mind, the N.A.A.S. initiated an investigation in 1950 to determine the most satisfactory method of sampling the fodder beet, using the variety Red Otofte. Their results (unpublished) indicated that both the diagonal- and horizontal-core methods of sampling may give a fair assessment of dry-matter content. The N.A.A.S. results, however, did not add to the knowledge of the dry-matter distribution within the individual root.

Experimental.—Because of the importance of this distribution in relation to the sampling and analysis of fodder beet the present investigation was undertaken. The roots used were from varieties representing each recognized dry-matter group of the fodder beet, viz. Hunsballe X (high), Red Otofte (intermediate), and Barres Otofte (low), grown at the King's College Experimental Station at Cockle Park. Individual specimens were selected at random from randomized plots of fodder beet,

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

grown in the 1952 season on a uniform site on Mid Tower Hill field. The roots used were rather small, because growth conditions were only moderate in that season.

Twenty roots from each dry-matter group were cleaned carefully and topped to remove all leafy parts. They were then marked to give a series of $\frac{1}{2}$-in. horizontal sections, together with a vertical section of $\frac{1}{2}$-in. thickness passing through the centre of the root. One side of the root was marked to facilitate future numbering (Fig. 1*a*).

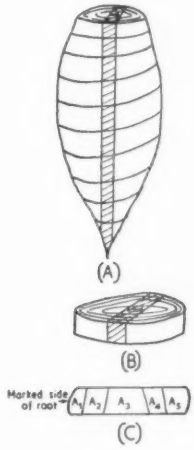

FIG. 1. Marking and sectioning of roots.

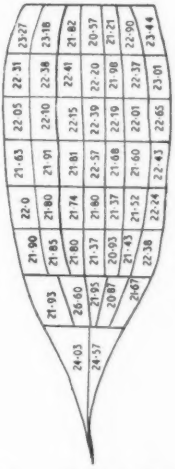

FIG. 2. Typical dry-matter distribution for one variety (Hunsballe X). (D.M. values = per cent. on fresh wgt. means of 6 roots).

In this way a series of sections of $\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in. $\times$ diameter was cut from the root (Fig. 1*b*). The sections were then subdivided into 2, 3, 5, or 7 pieces according to the width of the root (Fig. 1*c*). The dimensions and position of each piece were recorded and the dry-matter content was determined, drying at 100° C. for 48 hours and weighing to 0·001 gm. accuracy.

The results were then recorded diagrammatically and to scale as is shown in Fig. 2. A series of such figures was prepared, three for each variety, each figure being an average for six roots of similar size. It is not possible to reproduce all the figures here, but the main results are summarized in Table 1, which gives averages based on the larger roots in each variety. Successive horizontal sections are numbered from top to bottom, and vertical strips from left to right across the diameter of the root.

The distribution of dry matter within the roots showed both vertical

and individual variation. There were some characteristics, however, which appeared to be common to all roots and varieties.

There was usually a band of high dry-matter content at the crown of the root, with a fall in dry matter below the crown, followed by a gradual subsequent increase towards the root tip.

The centre of the root showed a lower dry-matter content than the outside layers, even in the high dry-matter region of the crown. The dry matter of the central vertical section did, however, show a steady increase from the crown towards the root tip.

The tendency of the outside of the root to be higher in dry matter than the inner layers was associated with a greater 'ring density'. Quite often the dry matter of one side of the root was slightly higher than that of the other. This may be contrasted with Wood and Berry's findings of uniformity within the root in respect to side position.

TABLE 1. *Dry-matter Content of Fodder-Beet Roots: Averages of Horizontal Sections and Vertical Strips.*

(*as per cent. on fresh weight*)

Horizontal section No.	1	2	3	4	5	6	7	8	9	10	11
Variety:											
Hunsballe X	23·77	23·34	22·97	22·66	22·51	22·76	23·09	26·73	..	..	..
Red Otofte	19·29	17·69	16·94	16·81	17·05	17·58	17·72	19·17	19·23	22·04	28·23
Barres Otofte	18·73	19·33	18·87	18·98	19·73	20·04	20·49	21·27	23·48	..	..

Vertical strip No.	1	2	3	4	5	6	7
Hunsballe X	23·32	23·01	22·69	22·64	22·50	23·11	23·36
Red Otofte	19·56	17·68	16·45	15·88	17·37	18·02	18·92
Barres Otofte	21·64	19·78	19·21	18·01	19·38	19·39	21·06

The variety Hunsballe X showed a gradual decrease from the high dry-matter content at the crown as far as the mid-portion of the root, and then an increase towards the root tip. In the varieties Red Otofte and Barres Otofte, however, the dry-matter content declined more rapidly below the crown and subsequently showed a gradual increase towards the root tip.

Conclusions.—The dry-matter distribution of fodder-beet roots showed variation within varieties and to a less extent within individual roots of a particular variety. This latter variation was sufficient to indicate that at least twenty roots should be sampled in order to obtain a useful assessment of dry matter within the crop.

The concentration of dry matter within the root was related to ring density, the dry matter being high towards the outside of the root and towards the tip. Ring density in these regions is also high.

The results showed that in sampling fodder beet no simple core can be fully representative, but for comparative purposes a diagonal core would be best. In addition, they indicated that horizontal cores may give useful results when there is a predominance of rather long and narrow roots.

Summary.—An investigation into the within-root dry-matter dis-

tribution of the fodder-beet varieties Hunsballe X, Red Otofte, and Barres Otofte is described. The results showed marked variations in dry-matter distribution within the root; it was concluded that the best sampling procedure, for root dry-matter estimation, is a diagonal core, but that a horizontal core is also satisfactory.

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(Received 20 January 1955; as revised, 21 March 1955)

FURTHER EXPERIMENTS ON WITCHWEED CONTROL. II. THE EXISTENCE OF PHYSIOLOGICAL STRAINS OF *STRIGA HERMONTHECA*

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With Plate 8

THE existence of different strains of parasitic organisms, indistinguishable morphologically but differing in physiology and host preference, has long been recognized in both plant and animal pathology. Such differences have chiefly been observed in the bacteria and fungi. In studies of parasitism by higher plants it has been suggested that strain differences might account for the differing virulence with which various hosts are attacked by the same parasite in different districts, but so far the occurrence of such strains has not been clearly demonstrated.

The genus Striga (Scrophulariaceae), or witchweed, is perhaps the most extensively studied of these parasites, and it is known that many factors can influence the degree of damage caused to the host. Among them are:

1. *Date of sowing the crop.*—Saunders [1], working on *Striga lutea* Lour. (= *S. asiatica* (L.) O. Kuntze.), and Andrews [2], working on *S. hermontheca* Benth., have shown that there is an optimum time of sowing for a crop to be heavily attacked; crops sown earlier or later than the usual time will often escape the worst of the attack.

2. *Season.*—It has been noted in almost all field studies that some seasons have a much heavier incidence of the parasite than others. This may depend on:

3. *Rainfall or irrigation.*—A season of light rainfall is usually one of heavy attack, and vice versa. Under irrigation, the effect of light watering is the same [2]. More recent observations by the author suggest that the rainfall may be critical during the first 3 weeks of the crop's life.

4. *Soil.*—Though exceptions are known, lighter soils are more prone to become infested by Striga than heavier ones, perhaps because the lighter soils do not retain water so long. Very sandy soils are also usually less fertile than the heavier soils.

5. *Fertility.*—Although the effect of fertilizer on an infested poor soil is at first to increase both parasite and host, heavy doses seem to increase the resistance of the host [3, 4].

6. *Host variety.*—Attempts have been made to find either resistant varieties of host crops or resistant new crops. Varieties of Sorghum millets have been bred, possessing varying degrees of resistance, in Africa, India, and Burma. As some resistance occurs in almost all hosts evolved in countries inhabited by the parasite, the degree of infestation found on one host may not be repeated on another host or even on a different variety of the same host.

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It follows that many effects attributed to 'strains' of a parasitic species could be reproduced by interactions of other factors. This consideration, plus the fact that many so-called 'strain' differences have not been well defined, has made investigators reluctant to put forward claims which might later be shown to be completely unfounded.

Over the great plains of the central and north-central Sudan, with a comparatively wide range of rainfall, only two soil types predominate, viz., a heavy clay ('cotton soil'), very impervious to water and often swampy during the rains, found principally to the east of the White Nile; and a sandy ('Qoz') soil, found over much of Kordofan and Darfur. The distribution of staple millet crops north of lat. 12° N. corresponds closely with the soil types. On the clay soils *Sorghum vulgare* ('dura') has been the principal crop since earliest recorded times, perhaps the only one grown until recently, but on the sands *Pennisetum typhoideum* ('dukhn' or 'bulrush' millet) is the staple. The cropping of the sands is not quite so clear-cut, because a small amount of Sorghum has always been grown on the lower-lying parts, but Pennisetum has only been introduced on the clays since the immigration of West Africans attracted by the success of the Gezira Scheme.

In the Sudan, *Striga hermontheca* Benth. is widespread over both the sands and clays, growing on native vegetation where there are no crops, and building up very heavy infestations on areas of old cultivation. The small-flowered variant, described as *S. senegalensis* Benth., is found only on the sands, and when different soils and hosts are taken into consideration it seems to be identical with *S. hermontheca*, for complete ranges of flower sizes may be traced in the same field. It has long been known [5] that in the clay lands generally a change of crop on an infested field, from Sorghum to Pennisetum, will result in a Striga-free crop of the latter where the former could no longer grow successfully. This is likewise the French experience in West Africa [6]. It has also long been observed that on the Kordofan sands, where Pennisetum is very heavily attacked, Sorghum will give a crop on fields too heavily infested with Striga for the successful cultivation of Pennisetum. These striking interrelations of hosts and parasite suggested that the possible existence of strains of the parasite should be investigated.

Field Experiments

Two field experiments were laid down in 1953 in Kordofan, to test the effect of weed-killers upon infestation of Sorghum and Pennisetum millets by *Striga hermontheca*, one experiment being at Um Ruaba, on a Pennisetum-growing sand, and the other at Kadugli, on a Sorghum-growing valley-clay in the Nuba mountains. The results (Table 1) show that the two crops differed greatly in their degree of parasitism on the different soils; this might have been caused by strain differences or by interactions of the factors listed earlier. It is worthy of note that a very small percentage infestation of Pennisetum occurred on the Kadugli clay: this is contrary to Gezira experience, where the author has never seen Pennisetum attacked by Striga.

A further experiment was done in 1954, in unreplicated rows, to ascertain the susceptibility of various millets and grasses to Striga in the

TABLE 1. *Differences in Striga Infestation of Sorghum and Pennisetum in Clay and Sand Districts. Means of eight replicates treated with weed-killer or untreated*

Crop and treatment	*Percentage of infested holes*	
	Sand soil	*Clay soil*
Sorghum, untreated .	0·1	32·6
Sorghum, treated .	1·0	14·8
Pennisetum, untreated	12·0	0·25
Pennisetum, treated .	6·0	nil

Gezira and in Kordofan. As Table 2 shows, the attack of the Gezira Striga was confined to maize and the members of the subgenus Eu-Sorghum. (*Sorghum purpureo-sericeum* is of the subgenus Para-Sorghum, distinguished among other things by a different chromosome number.) The attack of the Kordofan Striga followed a different pattern; the most

TABLE 2. *Differences in Striga Infestation of a Variety of Tropical Crops and Grasses in Sand and Clay Soil Areas*

Host plant	*Percentage of infested holes*	
	Kordofan sand	*Gezira clay*
Sorghum vulgare, var.:		
Radar	0·9	4·7
Dwarf White Milo . .	1·5	4·9
Wad Fahl . . .	nil	30·2
Sorghum sudanensis . .	4·9	9·8
Sorghum purpureo-sericeum .	1·1	nil
Pennisetum typhoideum . .	12·6	nil
Eleusine coracana . . .	3·1	nil
Panicum miliaceum. . .	nil	nil
Zea mays	nil	6·8
Setaria italica (2 vars.) . .	nil	nil

susceptible Sorghum in the Gezira was the most resistant in Kordofan, Pennisetum was heavily infested, and Eleusine, a crop foreign to both areas, was only attacked on the sands. *Sorghum purpureo-sericeum* Aschers & Schwf., which grew well on the clay, was unattacked there but suffered a slight attack on the sands.

Pot Experiments

Samples of Striga seed were collected in 1953 at the Um Ruaba (sand) site from parasites growing on Pennisetum and on Sorghum. A third collection of seed was made at the same time in the Gezira from plants growing on Sorghum. These seeds, though immature, developed sufficient germination capacity by the summer of 1954 to be suitable for testing purposes, and they were used for the experiments that follow.

Experiment A.—Three batches of sixty 4-in. pots were filled with soils

of Um Ruaba sand, Gezira clay, and Blue Nile river silt origins, respectively. All soil was heat-sterilized before use. The six combinations of the following treatments were each applied to ten pots of each soil type:

(*a*) Striga seed from three sources, viz. Gezira Sorghum, Kordofan Sorghum, and Kordofan Pennisetum;

(*b*) Sown with Sorghum (Feterita 1931) or with Pennisetum (native Kordofan variety).

TABLE 3. (*a*) *Total Striga Seedlings per Ten Pots, in Experiment A:* (*b*) *Numbers of Macroscopically Visible Striga Seedlings per Pot at the End of Experiment C*

Striga origin	*Gezira Sorghum*		*Kordofan Sorghum*		*Kordofan Pennisetum*		
Host	*Sghm.*	*Pstm.*	*Sghm.*	*Pstm.*	*Sghm.*	*Pstm.*	
Series	*A*	*B*	*C*	*D*	*E*	*F*	*Total*
			(*a*) *Experiment A*				
Soil:							
Sand . .	93	50	3	16	6	31	199
Clay . .	91	24	2	2	3	30	152
Silt . .	64	28	4	9	8	6	119
Total .	248	102	9	27	17	67*	470
			(*b*) *Experiment C*				
Soil:							
Sand (i) .	(not sown)		3·3	15·8	1·8	15·3	. .
Sand (ii)† .	4·8	1·0	2·0	3·3	1·0	4·8	. .
Clay . .	4·5	nil	4·3	9·5	2·5	6·8	. .
Silt . .	13·0	0·3	8·3	20·5	6·0	28·0	. .

Sghm. = Sorghum; Pstm. = Pennisetum

* The differences between crops, except Series C and D, and between Striga seeds of different origins, were significant in Expt. A.

† Sand (ii) was sown 3 weeks later than the others and consequently developed a lighter infestation. Significance was not tested in Expt. C.

A standard measure (0·15 gm. approx.) of Striga seed was mixed with the soil in each pot. Three Sorghum or Pennisetum seeds were sown per pot, and watered immediately. No Striga seed originating from Pennisetum growing on clay soil was available.

After sowing on 22 September 1954, the pots were kept in the shade during the day and moved indoors at night in order to avoid extremes of temperature and to induce as high a germination rate as possible. On 13 October, after 3 weeks, all pots were washed out gently under water and the number of Striga seedlings per pot attached to the host roots was recorded. The germination rate was low because of the lateness of the season, and many pots, especially in series C, D, and E (Table 3) contained no germinated Striga. The square-root transformation had therefore to be employed in the statistical analysis, after adding 0·5 to the original values.

As Table 3 (*a*) shows, early attack by, and attachment of Striga seedlings occured, even with the greatest host resistance found in the field, that between Pennisetum and Gezira Striga where no emergent Striga is ever seen. The resistance of the host is thus based on a refusal of nourishment to the parasite rather than on an inability to supply the stimulus for the parasite's germination [cf. 1, 2]. Because the secretions from both Sorghum and Pennisetum were highly effective in bringing about germination of Striga seeds in artificial culture, it is considered that the differences seen were due to host-parasite relationships, and not to interactions between these and soil type. Gezira Striga made a significantly heavier attack on Sorghum than on Pennisetum; Kordofan Striga from Pennisetum made a significantly heavier attack on Pennisetum than on Sorghum; and Kordofan Striga from Sorghum grown on land previously carrying mainly Pennisetum was indifferent in its attack.

Experiment B.—Two batches of ninety 4-in. pots were filled with heat-sterilized Kordofan sand soil and with heat-sterilized Gezira soil respectively; forty-five pots of each batch were infested with 0·15 gm. of Striga seed of Gezira-Sorghum origin and forty-five with the same amount of Striga seed of Kordofan-Pennisetum origin. The Striga seed was that collected in 1953. Five pots of each of the soil-seed combinations were sown with one of the following nine millets or grasses.

Sorghum vulgare, var. Radar.
Sorghum vulgare, var. Dwarf White Milo.
Sorghum vulgare, var. Wad Fahl.
Sorghum purpureo-sericeum.
Sorghum sudanensis: Sudan grass.
Pennisetum typhoideum: Bulrush millet.
Eleusine coracana: Finger millet.
Panicum miliaceum.
Setaria italica.

The results for Setaria and Panicum, where the average germinated Striga amounted to less than one per pot under all treatments, probably because of poor host development, were discarded before statistical analysis. The differences between seed origins and between host varieties (at 0·1 per cent. level), and the interactions, soils × varieties (1·0 per cent.), and seed × origins × varieties (0·1 per cent.), were significant (Table 4). As the square-root transformation was used in the analysis a 'minimum significant difference' cannot be quoted, but the principal significant differences are indicated in the table. All crops were significantly more heavily attacked by the Gezira (clay) Striga except the Pennisetum, which was significantly more heavily attacked by the Kordofan Striga. The only significant differences between soils were shown by the crops Sudan grass and Radar. Radar is a variety of grain sorghum especially bred in South Africa and Rhodesia for its resistance, almost amounting to immunity, to *Striga asiatica*.

Experiment C.—Parallel with the small-pot Experiment A above, large (14 in.) pots were sown with Sorghum and Pennisetum and infested with seed of the same three origins, viz. Gezira Sorghum, Kordofan

Sorghum, Kordofan Pennisetum. The same three soil types were used as in Experiment A, and four pots were sown with each soil-crop-Striga combination. These pots were primarily intended for observation. Plate 8 shows a sample set of the six crop-seed combinations, growing in Gezira soil. The infestation was similar to that found in the small-pot experiments; as usual, no Striga whatever appeared above ground in the Pennisetum-Gezira Striga combination. At the end of this experiment all pots were washed out and all the macroscopically visible Striga plants were counted. The results given in Table 3 (*b*) were roughly parallel to those of Experiment A, and suggested that the Kordofan-Sorghum Striga was of a slightly different strain from the Kordofan-Pennisetum one.

TABLE 4. *Mean Number per Pot of Germinated and Attached Seedlings of Striga of Differing Origin, on Various Host Plants, in Experiment B*

Host plant	*Soil*		*Striga origin*	
	Clay	*Sand*	*Gezira*	*Kordofan*
Sorghum vulgare, var.:				
Radar	7·0	3·1*	8·2	1·9*
Dwarf Milo	3·3	3·5	5·6	1·2*
Wad Fahl	3·3	2·8	6·1	nil*
Sorghum sudanensis	6·0	2·6*	7·1	1·5*
Sorghum purpureo-sericeum	1·1	1·9	2·7	0·3*
Pennisetum typhoideum	2·4	4·0	2·2	4·2*
Eleusine coracana	1·2	0·5	1·6	0·7*
Panicum miliaceum†	0·7	0·3	0·9	0·1
Setaria italica†	0·5	0·4	0·3	0·3

* Difference within host plant significant.
† Not statistically analysed (see text).

Discussion

The field experiments strongly suggested that there are two strains of *Striga hermontheca* in the Sudan, one attacking Sorghum for preference, and the other, Pennisetum. However, in the field possible interactions of infestation with climatic and soil factors could not be ruled out. In the pot experiments Striga seed of different origins was grown with various crops in soils of different types, under otherwise uniform conditions. When strictly compared in this way, Striga seed collected from Sorghum in the Gezira infested Sorghum more severely than Pennisetum, but Striga seed collected from Pennisetum in Kordofan infested Pennisetum more severely than Sorghum: and this held good in each experiment and on different types of soil. The conclusion is inevitable that there were two different strains of Striga, differing in their ability to attack these (and other) crops.

Lewin [7] offered the first evidence for the existence of biological strains of *Striga asiatica*, in commenting that Sudan grass was so readily attacked in the Union of South Africa and in Southern Rhodesia as to be a valuable trap crop, whereas no attack on it had been observed in Northern Rhodesia. He described two fields where maize was moderately attacked, although on adjoining land Sudan grass grew completely

free of the parasite, and observed that in many areas the virulence of the attack on maize seemed to be correlated with the dominant native veld grass of the area, suggesting that strains of the parasite might acquire greater or less virulence in passage through different hosts. Though this is not impossible (cf. Table 3, series C and D), further investigation is needed before the idea can be accepted. Different natural dominant grasses indicate different ecological conditions, and variation in ecological conditions associated with dominance of different grasses may be sufficient to cause differences in the vigour of a single parasite strain relative to its host.

The phenomenon of strain differences may be related to some of the theories of 'debasement of the edaphoclimatic complex' which have been put forward, especially in West Africa by Portères [6, 8]. According to these, native agriculture follows a course of deterioration from the first opening of new land. Starting with the cultivation of Sorghum millets, which are presumed to have the highest fertility requirements, a stage is reached when soil exhaustion results in a seriously weakened crop, which then becomes susceptible to Striga attack. A change of crop to one of postulated lower fertility requirements, i.e. to Pennisetum millets, then results in an almost Striga-free crop, although the preceding Sorghum might have been heavily attacked. After some years, during which further exhaustion of the land is taking place, the Pennisetum crops become weaker and weaker, until eventually Striga again appears in force. Finally, the Pennisetum millet is replaced by *Digitaria exilis* Stapf. ('Fonio'), which has an even lower requirement of fertility for crop production. When the soil is too exhausted for this crop, signified again by a heavy Striga attack, no further cultivation is possible and the land must be abandoned.

This account of the role of Striga postulates, (1) that Striga is not a serious parasite in itself, but only appears upon a crop already weak as a result of poor soil conditions, and (2) that the fertility requirements of the crops concerned are in the order mentioned. It also takes no account of the fact, already mentioned, that in the Sudan the situation on the sandy areas is the reverse of that in West Africa, for it is a change from Pennisetum ('low fertility requirement') to Sorghum ('high fertility requirement') that reduces the Striga infestation. Postulate (1) has already been shown by the author to be untenable, because on the clay lands the use of weed-killers to control Striga has considerably increased crop yields [9]. Soil exhaustion is a serious factor, which is bound to occur under continuous cropping without manure, especially on the sandy soils, but as it is normally accompanied by a steady increase in Striga when grain is grown year after year it is difficult to discriminate between the two causes of loss of crop. On exhausted infested land under low rainfall very little Striga may actually appear because the over-parasitized crop seedlings die early. Postulate (2) may be correct, though the difference in fertility requirement between Sorghum and Pennisetum varieties may not be as great as it assumes. A more probable explanation of the West African situation is that various strains of the parasite exist, and that the successive failures of the first two millets are

Infestation of two host plants by different strains of Striga (Experiment C).

Left to right, treatments as follows:—

Gezira Striga from Sorghum growing on: A. Sorghum: B. Pennisetum
Kordofan Striga from Sorghum growing on: C. Sorghum: D. Pennisetum
Kordofan Striga from Pennisetum growing on: E. Sorghum: F. Pennisetum
(All growing in Gezira clay soil)

due to a building-up of strains specific to each crop in turn. On light soils this would be accompanied by a steady decrease in fertility.

In any reorganization of native agriculture from monoculture or random cropping to rotation, involving planning of the use of capital and labour, it is first necessary to ensure a subsistence crop (that is, almost everywhere, grain) which will not occupy all the available land and effort of the farmer. This is almost impossible if Striga infestation is heavy. Portères [6] has shown that simply changing the subsistence crop involves the risk of prolonging a monoculture (or 'linear cultural sequence') to the point at which irreversible soil deterioration sets in. If, however, the change of crop is made as part of a rotational system, it may help to suppress Striga, because Striga seeds, irrespective of strain, are germinated by both crops, whilst the reduction in numbers of flowering stems offers an opportunity of manual or other control, and the seeds which germinate and die on the new host represent a reduction of total infestation.

Physiological strains probably exist in other parasitic species of flowering plants. Some years ago, the Sorghum variety Radar was released for cultivation in southern Africa because of its resistance to *Striga asiatica*, but results were variable. The failures were attributed to outcrossing in farm-grown seed, but it seems reasonable to suppose that a variety of the host plant, which might have attained complete field resistance to one strain, could still lack resistance to another strain native to remote districts.

Summary

Sorghum millets are usually heavily attacked by *Striga hermontheca* on the clay soils of the Sudan, where Pennisetum millets are practically immune. The reverse is true on the sandy soils, where Pennisetum is heavily, and Sorghum only lightly attacked.

By collecting Striga seed of different origins, and using it to infest various crops growing in soils of different types under uniform conditions, the different behaviour of *Striga hermontheca* on these two soils was shown to be due to the existence of two strains of the parasite.

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(*Received 4 January 1955*)

THE EFFECT OF POTASSIUM-IODIDE FEEDING ON MILK PRODUCTION AND COMPOSITION, AND ON GENERAL CONDITION, IN THE EGYPTIAN BUFFALO

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NUMEROUS investigations have been reported in different parts of the world regarding the use of iodinated casein as a source of iodine for stimulating the milk yield of dairy animals. The results of these investigations have been quite variable, and it is unlikely that such substances will continue to be accepted as supplementary feeds for general use owing to the undesirable effects they have on the metabolic activities of the animals [1, 2, 3].

On the other hand, potassium iodide, besides being a simple inorganic salt, is easily available and contains an unvarying quality and quantity of iodine; it can conveniently be used as an iodine supplement in the ration of animals to ensure the proper functioning of the thyroid gland [4, 5].

Although studies were carried out by Oloufa *et al.* [6] on the effect of supplementing the ration with thyroprotein on the milk yield of buffaloes, and by Asker *et al.* [7] on the effect of the treatment (also using thyroprotein) on the composition of buffalo milk, no previous attempt has been made to study the effect of feeding potassium iodide on the milk yield, milk composition, and general condition of Egyptian buffaloes. The present work has therefore been undertaken in an endeavour to cover this particular aspect.

Experimental

The experiment was carried out at Marg Farm on a small herd of six pairs of buffaloes, each pair being selected as nearly as possible identical in age, calving time, stage of lactation, and milk production. The animals were divided into two representative and similar groups by drawing lots to determine which individual of each pair should belong to the particular group. One group formed the control, which continued on its usual diet, while each animal of the second group received in addition one tablet per day containing 120 mg. of potassium iodide.

The experiment was started on 11 April 1953, at which date milk production was closely similar in both groups (the difference did not exceed 300 gm. daily), and it was concluded on 30 November of the same year, when all the buffaloes had dried up.

The buffaloes were fed the normal rations according to their milk production, and were hand-milked twice a day. The milk yield was recorded daily, morning and evening, in kilograms.

A representative sample of both morning and evening milkings was taken weekly for the estimation of acidity, specific gravity, fats, solids

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

TABLE 1. *Differences in Milk Yield and Length of Milking Period Between Iodine and Control Groups*

Treatment	Serial Number of pair												
	1		2		3		4		5		6		
	Milking period (weeks)	Milk yield (kg.)	Milking period (weeks)	Milk yield (kg.)	Milking period (weeks)	Milk yield (kg.)	Milking period (weeks)	Milk yield (kg.)	Milking period (weeks)	Milk yield (kg.)	Milking period (weeks)	Milk yield (kg.)	Total milk yield (kg.)
Iodine . .	23	1,099·2	33	1,617·5	11	568·7	15	357·7	19	414·2	17	457·3	4,514·6
Control . .	23	969·8	33	1,278·1	11	422·8	15	267·8	19	378·2	17	408·7	3,725·4
Difference . .	..	+129·4	..	+339·4	..	+145·9	..	+89·9	..	+36·0	..	+48·6	+789·2
Further effect of Iodine . .	+5	+68·3	+1	+5·3	+22	+786·3	+2	+8·0	−4	−51·9	+3	+25·1	+841·1
Over-all excess in milk yield (kg.)	..	+197·7	..	+344·7	..	+932·2	..	+97·9	..	−15·9	..	+73·7	+1,630·3

other than fats, and total nitrogen. The nitrogen distribution was also determined.

The temperature of each animal was recorded daily, morning and evening, and its pulse rate was also recorded, thirteen times for each animal, at intervals during the milking period. The animals were kept under close observation by a veterinary surgeon during the whole period of experimentation.

Methods of analysis.—The specific gravity was determined by using an accurate Quevene lactometer at 60° F., and the acidity (as per cent. lactic acid) by titrating with an N/9 solution of sodium hydroxide using 0·5 per cent. phenolphthalein indicator. The determination of fat was by the original Gerber method; that of non-fatty solids by evaporating 2 gm. of milk at 100° C.; and that of total and casein nitrogen by the semi-micro method described by Rowland [8].

Results and Discussion

Milk production. (*a*) *Effect of iodine feeding on milk yield.*—This is shown in Table 1, where the upper part of the Table gives the total milk yields up to the time when one of the pair dried up, and the lower part shows the excess in lactation of its companion animal after this point

TABLE 2. *Analysis of Variance, Effect of Iodine on Milk Production and on Persistency of Lactation*

Source of variation	*Degrees of freedom*	*Milk production*		*Persistency of lactation**	
		Sum of squares	*Mean square*	*Sum of squares*	*Mean square*
Effect of iodine .	1	2,639	2,639†	0·03807	0·03807 (N.S.)
Effect of grouping .	5	35,646	7,129	0·02935	0·00587
Error . . .	5	811	162	0·15993	0·03199
Total . .	11	39,096	..	0·22734	..

* Log transformation.
† Significant at P = 0·001; N.S. = not significant.

was reached. The difference between the two buffaloes in each pair, as shown in the upper part of Table 1, indicates that in every pair the iodine-treated animal produced more milk than the control one. The percentage increase of milk yield due to iodine feeding ranged between 10 and 34 per cent., with an over-all increase of 20 per cent. This finding was in general agreement with those of other workers using iodized protein as a source of iodine [9, 10, 11]. The results reported by Oloufa *et al.* [6], using thyroprotein on Egyptian buffaloes, were considerably lower than those obtained in the present study (i.e. an average increase of 4·2 per cent.). However, it was suggested that this low percentage increase might be due to the small dosage of thyroprotein used, or to the short duration of the experiment.

Perusal of the lower part of Table 1 shows that five out of the six iodine-treated buffaloes continued to lactate after their respective control

animals had dried up. This longer lactation period, with the excess of milk yield obtained, was presumably due to the effect of iodine feeding, particularly in pairs No. 1, 2, 4, and 6. The iodine-treated animal in pair No. 3 had an exceptionally long lactation period, as opposed to its control animal which dried up after a very short time of lactation: with the latter animal it is thought that other factors had intervened.

Analyses of variance, shown in Table 2, were carried out on the yield results that appear in Table 1. The effect of iodine as potassium iodide on the milk yield was very highly significant. The group mean square was also very significantly different from the error mean square. This was to be expected, since in the original plan of the experiment levels of

TABLE 3. *Effect of Iodine on Average Composition of Milk*

	Control	*Iodine-treated*	*S.E.* ±
Acidity %	0·150	0·161*	0·002
Sp. gr. at 60° F.	1·0329	1·0335*	0·0002
Fat %	7·58	7·28*	0·06
Solids not fat	9·58	9·98*	0·04
Total N %	0·663	0·679	0·08
Casein N %	0·515	0·527	0·005
Alb., glob., and proteose N %	0·103	0·109	0·002
Non-protein N %	0·044	0·043	0·0006
Casein No.	77·75	77·65	0·23

* Significant at P = 0·05.

production as different as possible were included in order to test the response of milk yield to iodine feeding under different conditions.

(*b*) *Effect of iodine feeding on persistency of lactation.*—It has been generally recognized by workers on persistency that lactation follows a hyperbolic course of the form (Ae^{bt}), at least in the declining segment of the lactation curve [12], where A represents initial yield, b the relative change in yield, and t time. Since one of the main objects in this part of the study was to measure the effect, if any, of iodine feeding on persistency of lactation, the yields were transformed to their logarithmic values, and differences between successive logs were obtained. These differences were, in fact, the logs of yield variation between two successive observations. Ordinary analysis of variance was done on the values thus obtained, and the results are given in the second part of Table 2.

The effect of iodine feeding on persistency of lactation, as shown in this table, failed to reach the 5 per cent. significance level. It was apparent, however, from actual observation that the response to iodine feeding took place only after a time-lag, which fact, together with the variability of individual buffaloes, may explain the failure to reach significance.

Composition of milk.—Table 3 shows the means and standard errors of various determinations of milk composition in both the iodine and the control groups. The acidity, specific gravity, non-fatty solids, total

nitrogen, casein nitrogen, and albumin-globulin-and-proteose nitrogen of the milk of the iodine group were all higher than those of the control group.

The differences were 0·011 per cent. for acidity, 0·0006 for specific gravity, and, in per cent., 0·40 for non-fatty solids, 0·016 for total nitrogen, 0·012 for casein nitrogen, and 0·006 for the albumin-globulin-and-proteose nitrogen. The differences for the acidity, specific gravity, and non-fatty solids contents were statistically significant at the 5 per cent. level.

On the other hand, the fat content, non-protein nitrogen, and casein number were lower in the milk of the iodine group than in that of the control group. The differences were 0·3 per cent. for fat, 0·001 per cent. for non-protein nitrogen, and 0·1 per cent. for the casein number. Only the fat-content difference was statistically significant.

TABLE 4. *Differences in Total Quantity of Butterfat Between Iodine and Control Groups*

(*Butterfat in kg.*)

Milking period	*Iodine group*	*Control group*	*Difference*
Fixed period . .	324·6	280·5	44·1
Excess-lactation period	64·2	3·8	60·4
Total . . .	388·8	284·3	104·5

The present results agree to a certain extent with those found by Asker *et al.* [7], who reported a higher specific gravity, and a higher content of protein, total solids, and non-fatty solids in the milk of thyroprotein-treated buffaloes than those of the control group. The differences apparent, however, were not statistically significant owing to the low dosage of thyroprotein used, the small number of animals treated, and the short duration of the experiment. Oloufa *et al.* [6] reported that the butterfat percentage of buffaloes' milk was higher during the treatment period, in both the thyroprotein and control groups, than it was during the pre-treatment period. The butterfat in the former period was 6·53 per cent. for the control group and 6·35 per cent. for the thyroprotein-fed group, while the respective percentages in the latter period were 6·06 and 6·01. Thyroprotein thus lowered the butterfat content during the period of treatment.

The total quantity of butterfat produced, shown in Table 4, was calculated in the same manner as the milk yield presented in Table 1. The results in Table 4 show that the total production of butterfat of the iodine-treated group increased during the fixed period by 15·7 per cent. above that of the control group, in spite of the fact that the fat percentage was significantly lower in the former than in the latter group. This result was clearly due to the increase in the milk yield resulting from iodine feeding.

General condition.—It has been reported that feeding cows with thyroprotein has the effect of speeding up metabolism, accelerating the

respiration and pulse rates, and raising the body temperature [1, 2, 3]. The same effect has also been reported in Egyptian buffaloes by Oloufa *et al.* [6]. The difference between the thyroprotein-treated and untreated animals in the above-mentioned work was not statistically significant.

In the present study, however, no effect on body temperature, or on pulse rate, was noticed following the administration of potassium iodide. The means of body temperature were 38·3° C. in the morning and 38·3° C. in the evening for the iodine group, while the means for the control group were 38·2° C. and 38·3° C. respectively. The mean pulse rate was 46 per minute in both the iodine and the control groups.

Summary

Twelve buffaloes in mid-lactation were chosen so as to give six comparable pairs, which were divided at random into two equal groups. One group served as the control, while each animal of the other group received daily a tablet containing 120 mg. of potassium iodide. This treatment was continued until lactation ceased.

The effect of feeding with this salt on the milk yield and composition, and on the general condition of the animals, was studied, and the following results were apparent:

Potassium-iodide feeding resulted in an over-all increase of approximately 20 per cent. in the milk yield of the treated group.

Potassium-iodide feeding significantly increased the percentage of solids-not-fat, as well as the specific gravity and the acidity of the milk, while on the other hand it significantly decreased the fat percentage.

The total production of butterfat of the iodine-treated group was increased by 15·7 per cent. over that of the control group, although the butterfat percentage in the milk of that group was lower.

Body temperature and pulse rate were not affected by the treatment.

Acknowledgement.—Our thanks are due to Mr. M. Ibrahim, Statistical Advisor, National Production Council, Cairo, for his valuable statistical advice.

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(*Received 9 November 1954; as revised, 28 March 1955*)

XUM

A FERTILIZER EXPERIMENT WITH NAPIER GRASS

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THE survey manurial experiments on tea initiated in 1950 by the Tea Research Institute of East Africa [1] included a mulch treatment of 20 tons (fresh weight) per acre of Napier grass, *Pennisetum purpureum* K. Schum. At Kericho the grass was grown for the purpose, and the opportunity was taken of carrying out a manurial experiment in order to obtain information on the local nutrient requirements of the crop. The aim being the production of mulching material, not high-quality fodder, cutting was relatively infrequent.

The design of the experiment was a 2^4 factorial one in two blocks of eight plots, the highest-order interaction NPKL being confounded. Treatments were, per acre: lime, a single application of 1 ton; and, annually, nitrogen, 50 lb. (as 250 lb. sulphate of ammonia); phosphate, 30 lb. P_2O_5 (as 166 lb. single superphosphate); and potash, 40 lb. K_2O (as 67 lb. of 60 per cent. muriate).

Other experimental details were: size of plot, one-eighth acre (approx. 60 × 90 ft.); the grass was planted in rows 6 ft. apart; it was cut when fairly mature, just before elongation of the cane.

The cuttings of grass were taken as in the following diary of the experiment:

1950,	10 May.	Lime applied to the previously ploughed and weeded plots.
	25 May.	Grass planted.
	8 August.	Fertilizer applied.
1951,	12 February.	First cut.
	3 July.	Second cut.
	8–9 August.	Second application of fertilizer.
	30 November.	Third cut.
1952,	9–10 May.	Fourth cut.
	21 July.	Third application of fertilizer.
	13–14 November.	Fifth cut (P_1 plots).
	12 December.	Fifth cut (P_0 plots).
1953,	20–21 July.	Sixth cut.
	8 August.	Fourth application of fertilizer.
1954,	15 March.	Seventh cut.
	26–27 July.	Eighth and last cut.

Soils.—The soil of the field on which the experiment was conducted is typical of the Kericho tea-growing area. It comes under the category described by Milne [2] as red earths laterized on various parent rocks, very freely drained, leached, and acid (cf. Eden [3]). Analyses of samples taken from the sixteen plots, on 4 and 5 January 1952, are reported elsewhere [4].

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

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TABLE 1. *Yields of Napier Grass, in Presence and Absence of Main Treatments*

(as lb. dry weight per acre)

Date of cutting	*Nitrogen 50 lb. per acre annually*			*Phosphate 30 lb. P_2O_5 per acre annually*			*Potash 40 lb. K_2O per acre annually*			*Lime 1 ton per acre one application*			*Significant differences*	
	+	−	*Difference*	+	−	*Difference*	+	−	*Difference*	+	−	*Difference*	P = 0·01	P = 0·05
12 Feb. 1951	4,829	4,790	+39	5,936	3,683	+2,253*	4,498	5,121	−623	4,652	4,967	−315	3,056	1,843
3 July 1951	5,295	4,670	+625	6,224	3,741	+2,483†	4,632	5,333	−701	5,022	4,943	+79	1,183	713
30 Nov. 1951	6,981	5,978	+1,003	8,914	4,045	+4,869†	6,331	6,628	−297	6,840	6,119	+721	1,949	1,175
9–10 May 1952	2,999	2,852	+147	3,567	2,284	+1,283†	2,815	3,036	−221	2,970	2,881	+89	1,281	772
13–14 Nov. 1952	5,236	4,521	+715*	6,958	2,799	+4,159†	4,948	4,809	+139	5,033	4,724	+309	1,034	624
20–21 July 1953	5,688	6,021	−333	7,985	3,724	+4,261†	5,850	5,859	−9	6,007	5,702	+305	1,610	971
15 Mar. 1954	4,834	4,481	+353	6,222	3,093	+3,129†	4,847	4,468	+379	4,779	4,536	+243	1,455	877
26–27 July 1954	2,223	2,498	−275	2,991	1,730	+1,261†	2,305	2,416	−111	2,430	2,291	+139	518	340
	38,085	35,811	+2,274	48,797	25,099	+23,698	36,226	37,670	−1,444	37,733	36,163	+1,570	..	..

Average production per acre per year: 9,237 lb. dry matter.

* Significant at P = 0·05. † All phosphate differences significant at P = 0·01, except 1st cut.

Experimental Results

Main effects (Table 1): *Phosphate.*—Throughout the trial there has been a highly significant response to phosphate application. The aggregate increase of crop due to phosphate was 94 per cent.

H. F. Birch [5] has established a relationship between phosphate response and base saturation in acid soils, and it may be observed that the average pH and per cent. saturation of the base exchange capacity of soil from the area covered by the present trial were respectively 5·05 and 39 per cent.

Nitrogen.—Only with the fifth cut did nitrogen give a significant response at the P = 0·05 level, though the increment due to nitrogen at the third cut approached significance.

TABLE 2. *Nitrogen and Phosphate Interactions in Different Seasons*

(lb. dry weight, totals of 4 plots)

Cuts 1 and 2 (1951)				*Cuts 3 and 4 (1951–2)*			
	P_0	P_1	P_1-P_0		P_0	P_1	P_1-P_0
N_0	3,495	5,965	+2,470	N_0	2,903	5,927	+3,024
N_1	3,929	6,195	+2,266	N_1	3,426	6,554	+3,128
N_1-N_0	+434	+230	−204	N_1-N_0	+523	+627	+104
Sig. Diff. (P = 0·05), 2,043				Sig. Diff. (P = 0·05), 646			

Cuts 5 and 6 (1952–3)				*Cuts 7 and 8 (1954)*			
	P_0	P_1	P_1-P_0		P_0	P_1	P_1-P_0
N_0	3,385	7,157	+3,772	N_0	2,751	4,228	+1,477
N_1	3,138	7,786	+4,648	N_1	2,072	4,985	+2,913
N_1-N_0	−247	+629	+876	N_1-N_0	−679	+757	+1,436
Sig. Diff. (P = 0·05), 1,080				Sig. Diff. (P = 0·05), 914			

A number of observers in the tropics [6, 7, 8] have reported that the effect of sulphate of ammonia is most apparent in the first cutting or two after application. Coetzee [9] in South Africa recommended that 'Occasional applications of sulphate of ammonia at the rate of 200 lb. per morgen (2·12 acres) will serve to put on growth when required.' The present results gave similar indications, the two largest responses (significant or nearly so) both following about four months after fertilizer applications.

Potash and lime.—No significant responses were obtained to potash or lime. Only one application of lime, however, was made; top-soil samples from the limed plots, taken on 4 and 5 January 1952, averaged pH 5·31 (unlimed 5·05), and percentage saturation of the base exchange capacity 46 (unlimed 39 per cent.). There is a slight indication that heavier or repeated lime applications would have shown some effect.

Interactions.—A significant (P = 0·05) positive interaction of nitrogen

and phosphate was found for the 5th, 7th, and 8th cuts. The trend of this interaction is well brought out by the annual totals, i.e. the totals of the two cuts following each application of fertilizers (Table 2).

In Jamaica, Ellis and Burrowes [10] reported an NP interaction in experiments with Napier grass. Holme and Sherwood [8], with pasture grasses in the Kenya Highlands, also reported a positive interaction between the two fertilizers sulphate of ammonia and superphosphate, which became more important with increasing dressings of nitrogen.

At the second cut there was a significant negative interaction of phosphate and potash (Table 3). The depressing effect of potash on the response to phosphate was not observed subsequently, and may have been fortuitous.

Composition of the grass.—Total nitrogen (by Gunning's method) and P_2O_5 (by a modification of the colorimetric method of Fiske and

TABLE 3. *Phosphate and Potash Interaction (2nd cut)*
(lb. dry weight, totals of 4 plots)

	P_0	P_1	P_1-P_0
K_0	1,838	3,495	+1,657
K_1	1,903	2,729	+826
K_1-K_0	+65	−766	−831

Sig. Diff. (P = 0·05), 713

Subbarow [11]) were determined on samples from each plot at every cutting. In conjunction with the yield figures the analytical figures give estimates of the recoveries of nitrogen and phosphate by the crop; they are summarized in Table 4.

On the conventional assumption that the difference in uptake between the manured and unmanured plots represents what is derived from the fertilizer, the recovery of phosphate was evidently of a very high order. During the course of the experiment 120 lb. P_2O_5 were applied to the P_1 plots, and the crop from these contained 80·7 lb. more P_2O_5 than that from the P_0 plots, a recovery of 67·2 per cent. E. W. Russell referred to a recovery of 31 per cent., found on English grassland mown for young hay, as being 'high' [12].

The recovery of nitrogen was by no means negligible, amounting to 77·2 lb. out of 200 lb. applied, or 38·7 per cent. It is likely that more frequent applications of nitrogen, with more frequent cutting, would have been more effective. From the NP interaction figures (Table 2) it is clear that phosphate was the major limiting factor, and responses to nitrogen could be expected only when the available phosphate was at an adequate level. At the end of the experiment the plants were dying out on the phosphate-deficient plots.

The P_2O_5 content—ranging from 0·15 to 0·45 per cent., with a general weighted mean of 0·27 per cent.—was low compared with figures reported elsewhere [9, 13]. It must be remembered that the grass was cut fairly mature for use as a mulch, and not for fodder. Consequently also

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the nitrogen percentages were on the low side, ranging from 0·61 to 2·15 per cent., with a general weighted mean of 1·43 per cent. French [14] reported for young Napier grass a nitrogen content of 1·66 per cent., and for old grass (up to 8 ft. high, with anthers emerging)

TABLE 4. *Recovery of Nitrogen and Phosphate in Napier-grass Herbage*

(*a*) *Nitrogen Recovery*

	N_0			N_1			N_1-N_0
Cutting no.	*Crop lb.*	N % (*weighted mean*)	N *lb.*	*Crop lb.*	N % (*weighted mean*)	N *lb.*	N *lb.*
1	4,790	1·69	81·1	4,829	1·71	82·3	1·2
2	4,670	1·38	62·8	5,295	1·48	77·5	14·7
3	5,978	1·51	90·4	6,981	1·63	113·3	22·9
4	2,852	1·58	45·0	2,999	1·66	49·9	4·9
5	4,521	1·27	57·6	5,236	1·67	87·6	30·0
6	6,021	1·31	78·6	5,688	1·36	77·6	−1·0
7	4,481	0·89	39·7	4,834	0·88	42·5	2·8
8	2,498	1·33	33·3	2,223	1·57	35·0	1·7
Total	35,811	1·36	488·5	38,085	1·49	565·9	77·4

(*b*) *Phosphate Recovery*

	P_0			P_1			P_1-P_0
Cutting no.	*Crop lb.*	P_2O_5 % (*weighted mean*)	P_2O_5 *lb.*	*Crop lb.*	P_2O_5 % (*weighted mean*)	P_2O_5 *lb.*	P_2O_5 *lb.*
1	3,683	0·179	6·60	5,936	0·221	13·13	6·53
2	3,741	0·196	7·33	6,224	0·241	15·02	7·69
3	4,045	0·303	12·25	8,914	0·384	34·20	21·95
4	2,284	0·348	7·94	3,567	0·375	13·36	5·42
5	2,799	0·244	6·83	6,958	0·323	22·46	15·63
6	3,724	0·251	9·35	7,985	0·275	21·96	12·61
7	3,093	0·171	5·30	6,222	0·181	11·27	5·97
8	1,730	0·297	5·14	2,991	0·334	10·00	4·86
Total	25,099	0·242	60·74	48,797	0·290	141·40	80·66

1·24 per cent. Chaterjee *et al.* [15], studying the nitrogen content of Napier grass cut at different heights, found from 1·66 per cent. at 1 ft. to 0·78 per cent. at 6 ft., in the first year of planting, and much lower contents in a later ratoon crop. The literature contains other similar figures [16].

Through the courtesy of the Director, some spectrographic analyses were carried out at the East African Agriculture and Forestry Research Organization, Muguga, on the sixteen samples from the third cutting and also on some soil samples. In the third-cutting grass samples there were no differences due to treatments in potassium, calcium, or magnesium contents, but there were clear indications of a lower manganese content in samples from the phosphate-treated plots (Table 5).

Summary.—A fertilizer experiment with Napier grass was carried out at Kericho, Kenya Colony, from 1950 to 1954. The grass, grown for mulching, gave throughout a highly significant yield response to annual applications of 30 lb. P_2O_5 per acre; in one year, the first cutting after fertilizer application showed a significant response to 50 lb. of nitrogen per acre. The NP interaction was positive and significant in the last year. Recovery of P_2O_5 in the crop was unusually high, being over 60 per cent. for the whole period.

TABLE 5. *Manganese Content of Grass Samples from Third Cutting*
(*mg.-equiv. per 100 g. dry matter*)

Treatment	*Mn*	*Treatment*	*Mn*
0	0·68	p	0·48
n	0·75	np	0·38
k	0·78	pk	0·44
nk	0·91	npk	0·56
l	0·70	pl	0·37
nl	1·07	npl	0·51
kl	0·79	pkl	0·45
nkl	0·75	npkl	0·72
Mean	0·80	*Mean*	0·49

Acknowledgements.—Our best thanks are due to Dr. T. Eden, formerly Director, Tea Research Institute of East Africa, under whose guidance the experiment was originally laid out. We gratefully acknowledge the co-operation of the Kenya Tea Co., Ltd., who placed the area of cleared land at our disposal and provided the labour for the agricultural operations.

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DISEASE INCIDENCE AND YIELD VARIATION IN POTATOES GROWN FOR FIVE YEARS WITH ORGANIC AND INORGANIC FERTILIZERS

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IN a previous paper [1] an account was given of an experiment designed to compare the effects of organic and inorganic manures and fertilizers on the growth of the potato variety King Edward VII. The present paper is concerned with an analysis of pest and disease incidence in the same crops for the period 1950–4 inclusive, together with a study of the factors affecting yield variation.

Experimental.—Three manurial treatments, replicated fourfold in randomized blocks, were applied as follows:

C = Compost prepared from vegetable waste and farmyard manure;
A = Commercial inorganic fertilizers applied at the same rates of total N, P, and K as for C;
½C½A = one-half of the total N, P, and K applied as compost and one-half as inorganic fertilizers.

The rates of manuring for the first 4 years have already been given [1]; in 1954, the fifth year of the experiment, treatments were similar,

TABLE 1. *Manurial Treatments in 1954*

Treatment	*Fertilizer or manure*	*Dressing*		
		cwt./acre	*Equivalent to cwt./acre*	
A	Sulphate of ammonia	6·9	= N	1·42
	Superphosphate	3·5	= P_2O_5	0·56
	Sulphate of potash	5·4	= K_2O	2·62
		tons/acre	%	
C	Compost	7·4		
	Composition: Water		61	
	N (D.M. basis)		2·5	
	P_2O_5 ,,		0·98	
	K_2O ,,		4·6	
	Loss on ignition ,,		53·8	

although the applications of nitrogen and phosphate were smaller than in the previous years. All treatments were forked in before planting. The 1954 treatments and the composition of the compost are shown in Table 1.

Certificated Scottish stock seed tubers were grown in 1950, and thereafter tubers were returned annually to the same plots. No insecticides or fungicides were used at any time.

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

During the growing season, stem heights were recorded weekly on marked plants and counts were made of plants showing virus disease symptoms. The tubers were lifted in September of each year and the weights and numbers of washed tubers recorded. Both the weights and

TABLE 2. *Meteorological Data, Averaged for Periods Related to Potato Growth*

	Period	*1950*	*1951*	*1952*	*1953*	*1954*
Rainfall (inches) .	26 Mar.–3 Sept.	11·30	14·32	9·89	11·11	13·58
,, ,, .	23 Apr.–20 May	3·00	2·00	1·28	1·65	1·37
Sunshine (hours) .	23 Apr.–3 Sept.	927	941	1,015	976	751
,, ,, .	23 Apr.–20 May	155	155	213	214	186
Temperature						
,, (mean max., ° F.)	26 Mar.–3 Sept.	..	64	66	63	62
,, ,, ,,	23 Apr.–20 May	..	57	62	56	58
,, (mean min., ° F.)	26 Mar.–3 Sept.	49	48	49	48	46
,, ,, ,,	23 Apr.–20 May	43	42	45	42	42

the numbers of tubers showing the various types of pest and disease injury were noted. Meteorological data were compiled from the records of the College Department of Horticulture and are summarized in Table 2.

TABLE 3. *Crop Yields and Pest and Disease Incidence in Tubers at Lifting*

		Yield				*Percentage by weight*			
Year	*Treatment (see text)*	*Tons per acre*	*Least sig. diff. P = 0·05*	*Tubers per acre Thousands*	*Least sig. diff. P = 0·05*	*Blight*	*Black scurf*	*Wire-worm injury*	*Slug injury*
1950	C	10·4	1·12	232	36	5·9	Not determined		
	½C½A	16·0		249		17·7			
	A	15·5		199		17·5			
1951	C	8·8	0·95	184	28	4·0	8·1	10·0	14·2
	½C½A	12·2		209		7·3	7·6	8·2	6·6
	A	11·6		180		5·1	4·6	6·4	14·3
1952	C	4·7	0·75	208	32	Nil	27·9	19·6	28·9
	½C½A	6·0		205		,,	29·6	24·6	26·8
	A	5·5		192		,,	25·0	29·9	24·4
1953	C	9·4	1·63	177	43	1·0	16·8	23·4	36·2
	½C½A	9·3		166		1·3	22·7	18·0	38·6
	A	9·0		158		1·2	28·6	24·2	30·2
1954	C	8·4	3·45	127	48	11·3	0·2	17·4	49·2
	½C½A	6·4		108		18·5	0·5	14·8	55·5
	A	6·2		119		18·8	2·9	21·0	49·0

A summary of the yield results, and the incidence by weight of disease or damage in the tubers at lifting, is given in Table 3. In Fig. 1 the pest and disease incidence by number is summarized graphically. Yield results for the first 4 years have already been discussed [1]. In the first 3 years plants receiving only compost yielded less than those receiving inorganic fertilizers, but the differences became progressively less, and

in the fifth season the yield from the compost-treated plants was higher than from those receiving inorganic fertilizers although the difference was not significant.

Pest and Disease Damage in the Tubers at Lifting

The chief sources of injury were potato blight (*Phytophthora infestans*), black scurf (*Corticium solani*), slugs, and wire-worms. In addition to these, traces (<1 per cent. by number) of common scab (*Actinomyces*

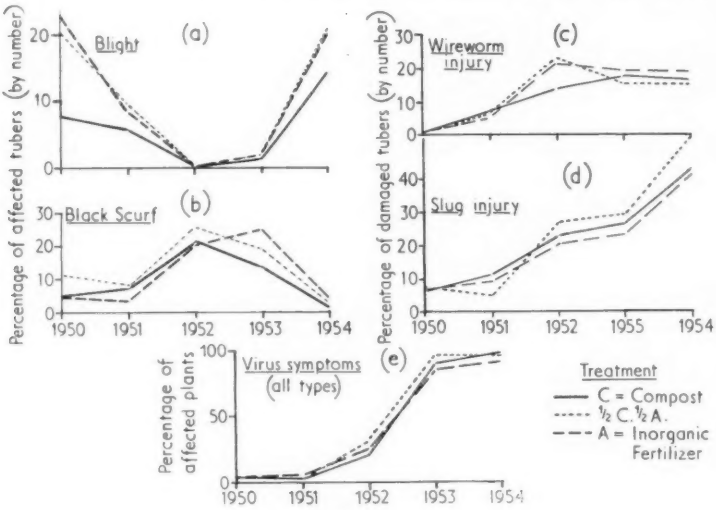

FIG. 1

scabies) were noted in 1950 and 1951 only, and up to 2 per cent. of the tubers were affected with dry rot (*Fusarium coeruleum*) in these 2 years, the last-named disease deriving from traces in the original Scottish seed.

Statistical examination of the results for numbers and weights of affected tubers was carried out, using the angular transformation for percentages [2]. The only difference between treatments which was significant was that for blight in 1950.

Blight.—In 1950 the percentage of blighted tubers, by weight and by number, from plots receiving compost only, was significantly less than from plots receiving inorganic fertilizers ($P < 0{\cdot}001$). The mean values for the 5-year period also showed this difference. In 1950 and 1951 it was noted that plants receiving only compost became relatively deficient in nitrogen 4–5 weeks after emergence [1]. It may be suggested that the observed relation between blight in the tubers and treatment was attributable, in part, to a deficiency of nitrogen in plants of the C series in July and August, although whether the relation was determined by a lighter infection of the shoots, associated with their premature senescence, or by greater resistance of the tubers, cannot be stated. The results accord with those of Gilbert [3] and Koblet [4] for the relations of nitrogenous

manuring to blight, but not with those of Schaffnit and Volk [5], who were, however, concerned with a gross deficiency of nitrogen in pot culture.

No simple relation could be shown between blight incidence in the tubers and any single meteorological factor. Van Everdingen [6] and others have indicated the complex of weather factors which may interact in determining blight attack in the leaves, so that this result was not unexpected. Only one blight-free year (1952) was noted with these unsprayed crops, although infection was light in 1953. Large *et al.* [7] have recently concluded that 3 years out of 10 may be expected to be blight-free in the Lincolnshire area.

Black scurf.—The incidence of superficial black scurf varied markedly from year to year (Fig. 1 and Table 3), being most abundant in the relatively dry, warm year of 1952 and least prevalent in 1954 when it was cool and wet. No significant treatment differences were found, but the mean percentage of affected tubers (by number) for the 5 years showed somewhat less disease where compost only was used (9·7 per cent.), as compared with $\frac{1}{2}C\frac{1}{2}A$ (13·3 per cent.) and A (11·6 per cent.).

Wire-worm damage.—Treatments had little apparent effect on wire-worm injury, and no simple correlation between injury and any single weather factor could be shown. The incidence of damaged tubers rose from a mean value for all treatments of 0·2 per cent. by number in 1950 to a maximum of 19·8 per cent. in 1952 and continued near this figure in 1953 and 1954. The fact that the plots were bordered with grass paths is likely to have been of importance in maintaining the wire-worm population.

Slug damage.—The incidence of slug damage increased throughout the experiment, and differences between treatments were small. Narrow plots separated by 12-inch grass paths would permit free movement of slugs between plots and the continued culture of potatoes would provide a ready source of food, even after lifting, since some small tubers inevitably remained in the plots throughout the winter. Conditions were thus ideal for the maintenance and increase of the slug population. No studies were made of either the species or the total numbers present.

Virus diseases.—Despite the difficulty of accurate diagnosis by visual symptoms it was thought worthwhile to record the numbers of plants affected by virus diseases. Three types of symptoms were distinguished, viz. leaf roll, leaf-drop streak, and a mosaic mottling of the leaves probably caused by Potato Virus Y.

In 1950 virus-free tubers were planted, and thereafter two tubers per plant were saved for 'seed'. In 1950, 1951, and 1952 tubers were saved from plants appearing virus-free, but in 1953 rogueing became impossible and tubers were then saved from all plants.

Leaf roll was the only symptom noted in 1950, after which its incidence declined. The incidence of leaf roll for all treatments was 4·7 per cent. in 1950, 2·4 per cent. in 1951, and 1·7 per cent. in 1952. In 1953 and 1954 leaf roll was less than 0·5 per cent. That leaf roll failed to establish itself in the crop may have been due in the first place to rogueing, and in later years either to absence of fresh sources of infection or to

some resistance in these heavily manured plants. There would appear to be no evidence that generous manuring can lead to masking of leaf-roll symptoms, and with Majestic potatoes there is some evidence to show that moderate dressings of dung (15 tons/acre) or of sulphate of ammonia (0·6 cwt. N/acre) may lead to an increased incidence of leaf roll in one season [8].

Leaf-drop streak and mosaic symptoms appeared in 1951 and then spread, until by August 1953 all plants showed one or the other symptom. Nevertheless, in 1954, a few plants were without visible symptoms of infection, at least until June. This type of infection thus followed its expected course, although because of rogueing in the first 3 years its development was somewhat slower than might have been predicted for a crop in east Kent.

The incidence of virus disease symptoms (all types) is shown in Fig. 1.

Factors Associated with Yield Variation

From the nature of the manurial treatments it was to be expected that seasonal variations in yield would be associated chiefly with climatic and disease factors, at least with the A and $\frac{1}{2}C\frac{1}{2}A$ treatments, in which

TABLE 4. *Maximum Stem Heights*

(*Means for 28 plants, in inches*)

Treatment	*1950*	*1951*	*1952*	*1953*	*1954*
C	23·9	20·4	15·2	20·4	19·4
$\frac{1}{2}C\frac{1}{2}A$	31·4	23·0	16·7	20·2	18·9
A	30·8	23·7	16·5	21·0	19·8
Least sig. diff., P = 0·05	1·8	1·8	2·2	1·8	3·2

TABLE 5. *Regression Equations of Yield on Rainfall and on Stem Heights*

Treatment	*Yield on rainfall*	*S.E.* ±	*Yield on stem height*	*S.E.* ±
C	$y = 2{\cdot}20x + 4{\cdot}25$	1·27	$y = 0{\cdot}67z - 4{\cdot}98$	0·11
$\frac{1}{2}C\frac{1}{2}A$	$y = 5{\cdot}68x - 0{\cdot}93$	0·78	$y = 0{\cdot}71z - 5{\cdot}62$	0·11
A	$y = 5{\cdot}75x - 1{\cdot}14$	0·75	$y = 0{\cdot}74z - 6{\cdot}50$	0·10

Where y = yield (tons/acre); x = rainfall, 23 Apr.–20 May (in.); and z = maximum stem height (in.).

nitrogen did not appear to limit growth at any time. Correlations were sought between yields and rainfall, hours of bright sunshine, and mean maximum and minimum temperatures, for periods covering intervals of from 1 to 24 weeks throughout the growing season. With $\frac{1}{2}C\frac{1}{2}A$ and with A, but not with C, a significant relationship was found between yield and rainfall for the 4-week period beginning 23 April, which included in all years the time when shoots appeared above ground. The maximum stem height was also found to be significantly correlated with yield and with rainfall during the same 4-week period. The stem heights are given in Table 4, and the regressions of yield on rainfall and on stem height are shown in Table 5.

Some relation can be expected to occur between yield and rainfall. With Majestic potatoes in Nottinghamshire [9] a close connexion was found in 6 years out of 8 between yield and total rainfall during the growing period. The relation shown in Table 5 between yield and early rainfall was very close for treatments A and $\frac{1}{2}C\frac{1}{2}A$. Since growth and yield must be determined to a great extent by supplies of available nutrients, the relation might be expected to hold only where these did not limit growth. In the early years in the C series, growth was limited by lack of nitrogen [1], and with this treatment the regression was not significant.

That such a close relation should hold despite an increasing incidence of virus diseases was surprising. Although it is not to be supposed that the virus diseases were without effect on yield, it might seem that the rainfall was of greater importance as a factor controlling yield.

TABLE 6. *Virus Incidence and Variability of Tuber Yield*

Year	*Number of virus-infected plants*	*Coefficient of variation, tuber yield*
	%	%
1950	5	4
1951	4	5
1952	24	8
1953	90	25
1954	94	29

The potential value of early irrigation in increasing yields is obvious, at least where adequate nitrogen, phosphate, and potash can be supplied. It should be stressed that the dressings of sulphate of ammonia applied in treatment A were in excess of those normally used commercially, although those applied in the $\frac{1}{2}C\frac{1}{2}A$ series did not greatly exceed the dressings applied by good growers.

There was a striking parallelism between the increasing virus incidence and the decreasing precision of the experiment throughout the years, as measured by the coefficient of variation $\left(\frac{\text{S.D. of single plot}}{\text{Mean}} \times 100\right)$ for the yield of tubers (Table 6).

There were significant correlations between early rainfall and maximum stem height as well as between stem height and yield. In cotton [10] stem height is closely correlated with yield from the time of thinning until harvest, and it has been used to predict yields in the Sudan. It is unlikely that much practical use could be made of this relationship in predicting potato yields, except under standardized conditions of planting date, soil type, variety, manuring, and cultural methods such as obtained in the present work. It is of interest that the regression of yield on stem height was significant for the C series also (i.e. where nitrogen was, by mid-season, a factor limiting growth), thus confirming earlier views that stem height is closely determined by the available supplies of nitrogen and water.

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Conclusions

This work was originally planned to investigate claims that the exclusive use of compost results in heavy, disease-free crops. The basis of this belief would seem to lie, primarily, in the large amounts of nitrogen which may safely be applied to crops in the organic form. Up to 50 tons of compost or farmyard manure per acre may be applied in horticultural practice, and this may contain nitrogen equivalent to 1 ton of sulphate of ammonia. Although not all of the nitrogen, phosphate, and potash are immediately available, it is unlikely that lack of any of these nutrients will limit growth after a few applications of this magnitude.

Water supply also may be ameliorated, by the effect of the organic matter on the water-holding capacity of the soil. In the present experiment differences in soil structure were evident between treated plots after 3 years. In the early spring, plots of the A series tended to dry out rapidly, forming a fine, crumbly tilth, in marked contrast to the sticky condition of the C series at that time.

Where nitrogen, phosphate, potash, and water are adequately supplied early in the season, the effects of leaf-drop streak and mosaic on yield would appear to be reduced, although further experiments to test this are called for. In the present work compost did not eliminate disease or pest attack, and no evidence was obtained for the presence of any special growth factors in compost [1]. It must be concluded that its effects may be adequately explained, at least in this experiment, in terms of plant nutrient and water supply.

Summary

Potatoes (King Edward VII) were grown continuously for five seasons, using 'seed' saved from the same plot in the previous year. The manurial treatments, compost, inorganic fertilizers, and half-and-half (half compost and half inorganic) were compared, observations of pest and disease attack being made during growth and at harvest.

Damage in freshly harvested tubers was caused primarily by potato blight (*Phytophthora infestans*), black scurf (*Corticium solani*), wireworms, and slugs. In the first season only, the incidence of blight in tubers grown with compost was significantly less than with inorganic fertilizers or with the half-and-half treatment, a result associated with the low level of available nitrogen in the compost series in that year. With blight in other years, and with the other pests and diseases in all years, the treatment differences were not significant.

Symptoms of leaf roll, leaf-drop streak, and mosaic due to virus infection appeared in all treatments. At the end of 4 years almost all the plants showed symptoms of either leaf-drop streak or mosaic (potato virus Y), despite rogueing. Leaf roll did not spread. There were no significant differences between treatments in virus incidence although tubers were returned annually to the same plots.

With inorganic fertilizers and the half-and-half treatment, yield was significantly correlated with the rain that fell during the 4-week period

that included 1 week before the first shoot appeared and 3 weeks thereafter. Regression equations for this relationship are presented. The regression was not significant for the compost series, in which nitrogen was known to have been limiting growth during the early years of the experiment.

With all treatments, yield was significantly correlated with the maximum stem height, and regression equations for the relationship are given.

Acknowledgements.—We are indebted to Mr. A. E. Maddison for advice on statistical treatment, and to Miss N. Lepper and Miss P. Rome for their careful assistance in harvesting and recording.

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(*Received 15 November 1954; as revised, 18 April 1955*)

THE HUMPS OF EAST AFRICAN CATTLE

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With Plates 9 and 10

THE hump is a prominent feature of Indian and many African cattle and a brief description of the structure as found in East African cattle may prove of interest.

The cattle of East Africa may be divided into two main types, the East African Shorthorned Zebu and the Sanga. The former is distributed throughout Kenya and most of Tanganyika and in the West Nile, Karamoja, and Bukedi areas of Uganda [1]. There are several local varieties of this type and of these the *Boran*, *Galla*, and *Tuni* deserve to be known as distinct breeds. The Sanga type is represented by the *Ankole* breed which is found in north-west Tanganyika and in the Western Province of Uganda.

The humps of these two cattle types differ in appearance, in structure, and apparently in function.

External Appearance

To quote a description given previously [2] 'the hump of the Shorthorned Zebu (Fig. 1, Pl. 9) is a prominent structure, situated dorsal to the vertebral border of the scapular cartilage. Both in size and in shape it varies in different animals and in the same animal at different times. From its cranial extremity the hump rises at an angle of about 45° to a rounded summit, when it descends at a varying acute angle to its caudal extremity. The somewhat domed shaped summit of the hump is frequently pendulous, lying over the caudal extremity of the hump.'

The hump of the *Ankole* (Fig. 2, Pl. 9) is much less prominent although it is often well marked in the bull. It is somewhat pyramidal in shape and occupies a more cranial situation than does the hump of the Shorthorned Zebu.

Structure

As hump formation depends on modifications in two muscles, the *Trapezius* and *Rhomboideus*, it is first necessary to describe these muscles in the unhumped bovine.

In these animals the *trapezius* muscle (Fig. 3) is thick and fan-shaped, the fibres of which take origin from the *ligamentum nuchae* and the supraspinous ligament, from the atlas to the level of the 10th to 12th thoracic vertebrae. The fibres converge cranially from the thoracic region and caudally from the cervical region to end in an aponeurosis which is inserted into the spine of the scapula. There is no division of the muscle

[1] This paper was intended to be the first of a series dealing with the physiology of the bovine hump, but it must now stand alone owing to the untimely death of the author in an aircraft disaster. Although this paper is chiefly anatomical, it is published in this Journal because it is likely to be of interest not only to veterinary anatomists but also to animal husbandry workers concerned with cattle in the tropics. *Editor.*

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91-92, 1955]

into cervical and thoracic parts as is found, for example, in the horse and dog.

The fibres of the *rhomboideus* muscle (Fig. 4) in unhumped cattle take origin from the *ligamentum nuchae* and the supra-spinous ligament,

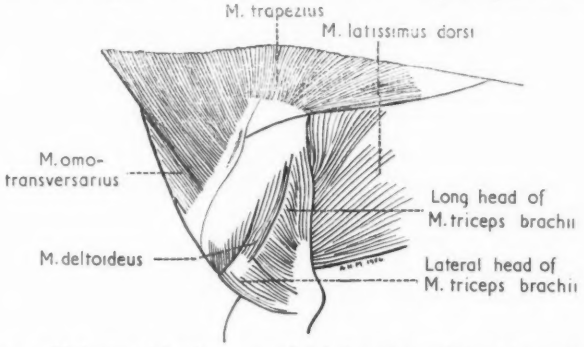

FIG. 3. Unhumped bovine: superficial dissection of shoulder region.

and are inserted on to the medial surface of the scapular cartilage. The muscle may be considered as consisting of two parts. The cervical part has roughly the shape of an elongated triangle, the apex being anterior, and the muscle fibres are arranged more or less longitudinally. The

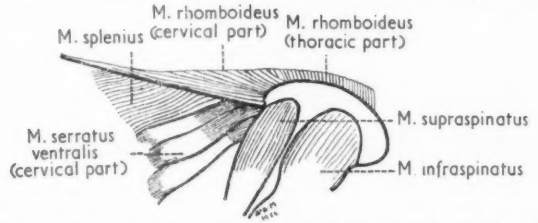

FIG. 4. Unhumped bovine: deep dissection of dorsal part of shoulder to show *rhomboideus* muscle (somewhat diagramatic).

relatively small thoracic part has its fibres disposed in a ventro-caudal direction.

These muscles are well developed in the bull, as are the *serratus ventralis* and *splenius* muscles, and in certain bodily postures, e.g. when the head is raised, a distinct prominence may be seen in the anterior cervical region. This, however, is not a hump in the generally understood sense of the term and has been referred to as a crest [3].

East African Shorthorned Zebu

In this type of animal the *trapezius* muscle (Fig. 5, Pl. 9) is distinctly divided into cervical and thoracic parts. The cervical part is thin and of a pale reddish-brown colour. Cranially it takes origin from the *ligamentum nuchae* from about the level of the 4th or 5th cervical vertebrae while more caudally it arises from the hump. The fibres converge

in a ventro-caudal direction to be inserted on to the line of the scapular spine. The function of this part of the muscle is to act as an attachment of the hump, which because of its fatty nature tends to be rather mobile. The thoracic part is somewhat fan-shaped and this part of the muscle is much thicker and darker in colour than the cervical part. It takes origin from the supra-spinous ligament from the level of the 12th or 13th forward to the level of the 6th or 7th thoracic vertebrae. Anterior to this the muscle fibres arise from the hump. The fibres converge in a ventro-cranial direction to end on an aponeurosis which is inserted into the spine of the scapula. This part of the muscle serves too, although to a lesser extent than the cervical part, as an attachment of the hump.

In the East African Shorthorned Zebu the *rhomboideus* muscle is completely modified, part of the muscle having undergone great development. There is in the unhumped animal no arbitrary division between the two parts of this muscle, and so the part which has been developed may be either the posterior portion of the cervical part, or the anterior portion of the thoracic part. In any case this developed portion forms a foundation and a muscular framework for the predominantly fatty hump (Fig. 6, Pl. 9), which may be described therefore as a musculo-fatty development of part of the *rhomboideus* muscle.

The cranial extremity of the hump lies constantly over the 7th cervical or 1st thoracic vertebra—usually the latter—but the relation of the caudal extremity of the vertebral column appears to vary. Curson and Bisschop [3] state that the hump lies over the 1st to 9th thoracic spines, but the present author in a previous paper [2] gave the 6th thoracic spine as the most caudal limit of the hump. This statement was based on a considerable number of observations, but since then humps have been dissected the caudal extremities of which did lie over the 9th thoracic spine.

The hump of the East African Shorthorned Zebu is, then, thoracic in situation and musculo-fatty in structure (Fig. 7, Pl. 10), and it appears that this type of hump represents an accumulation of reserve food material.

In foetuses the hump is well marked (Fig. 8, Pl. 10). The youngest foetus so far examined was estimated to be about 50 days old and already the hump was quite distinct and definitely thoracic in position. Examination of sections of foetal humps at this Laboratory tends to indicate that fat begins to be laid down in the hump at about the third month of foetal life.

Ankole (*Sanga Type*)

Although in the *Ankole* the *trapezius* muscle is not arbitrarily divided as in the Shorthorned Zebu, there is no difficulty in distinguishing cervical and thoracic parts. The cervical part resembles the corresponding part in the Shorthorned Zebu. It is a very thin sheet of muscle which arises from the *ligamentum nuchae* from about the level of the 2nd or 3rd cervical vertebra. Caudally it becomes closely associated with the surface of the hump as an aponeurotic layer. The fibres run in a ventro-caudal direction to end on the line of the scapular spine. The thoracic

part is much more fleshy. It takes origin from the supra-spinous ligament. From the level of the 12th–9th thoracic vertebrae the origin is by an aponeurosis, but cranial to this the fibres themselves originate from the supra-spinous ligament. The muscle fibres run in a ventro-cranial direction, and cranially they blend with the aponeurotic layer lying over the hump. Ventro-cranially there is an aponeurotic insertion on to the tuber scapulae (Fig. 9, Pl. 10).

The *rhomboideus* muscle is clearly divided into two parts. The cervical part is much enlarged and forms the actual hump. The muscle fibres are disposed in a longitudinal direction and the muscle bundles of each side

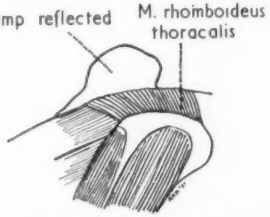

FIG. 10. *Ankole*: dissection to show thoracic part of *rhomboideus* muscle (somewhat diagramatic).

are separated by a medial fibrous septum. Caudo-ventrally the hump is inserted on to the lateral aspect of the cranial angle of the scapular cartilage by a fibrous ligament. The hump is also attached, by a fleshy insertion, on to the medial aspect of the cranial angle of the scapular cartilage.

The hump lies, in relation to the vertebral column, from the 4th or 5th cervical to the 4th thoracic vertebrae. It is, then, a cervico-thoracic hump, and it is purely muscular in structure, not musculo-fatty as in the Shorthorned Zebu. In view of its firm and double attachment to the scapula its function is probably to assist in the movement of the fore-limb.

The thoracic part of the *rhomboideus* muscle (Fig. 10) is very much smaller than the enlarged cervical part. It takes origin from the supra-spinous ligament from the level of the 1st–7th thoracic vertebrae, and the fibres run in a ventro-caudal direction to be inserted on to the medial surface of the scapular cartilage along its whole length.

Discussion

The important differences between the humps of the two types of East African cattle may be tabulated thus:

	E.A. Shorthorned Zebu	*Ankole (Sanga)*
Situation . .	Thoracic	Cervico-thoracic
Structure . .	Musculo-fatty	Muscular
Function . .	Fat storage	Locomotory

The foundation stock of African cattle is said to have been threefold, viz. the humpless Hamitic Longhorn; *Brachyceros*, also with no hump;

and the Lateral-horned Zebu which has a hump, and is represented today in South Africa by the Afrikander [4].

The Lateral-horned Zebu is supposed to have entered Africa about 2,000 years B.C., and exerted a profound influence on the cattle in Upper Egypt, especially on the Hamitic Longhorn. From the crossing of these two types arose the Sanga. This view is supported by the fact that the hump of the Sanga type bears a strong resemblance to that of the Afrikander [3], both humps consisting of an enlarged *rhomboideus cervicus* muscle and both being entirely muscular.

The Shorthorned Zebu was considered by Epstein [5] to have been derived in Asia from the influence of *Brachyceros* on the Lateral-horned Zebu. As *Brachyceros* is humpless and the Lateral-horned Zebu had a purely muscular hump, if Epstein's theory is correct it is interesting to speculate as to when the remarkable musculo-fatty hump of the East African Shorthorned Zebu arose.

Ware [6], writing of Indian cattle, states: 'Another suggested classification of the Zebus is by the position of the hump which may be either cervico-thoracic and muscular, or thoracic and musculo-fatty. If this classification is adopted all present-day Indian cattle will fall into the latter class with the exception of the Siri breed of Bhutan.'

This is not supported by the work of Thorpe [7], who gave a good account of the hump of a bovine which he describes as 'a Zebu cow of the Gujerat type'. The hump which Thorpe describes is a purely muscular one, and indeed his description closely tallies with the one given above for the *Ankole* hump.

Furthermore, work at present going on at this Laboratory shows that the introduction of *Sindhi* and *Sahiwal* blood into local Shorthorned Zebu stock significantly reduces the amount of fat in the hump.

Epstein [5] writes: '. . . in some less accessible parts of Southern India, Longhorned Zebu breeds may exist that have preserved their original structure for thousands of years just as the Afrikanders' ancestors have.'

Whether or not this is so, it is obvious from Thorpe's description that some types of Indian cattle are possessed of humps of the Sanga or Lateral-horned-Zebu type.

Ware [6], discussing Epstein's theory of the origin of the Shorthorned Zebu, makes the statement that no specimens of the Lateral-horned Zebu had been found in India unless one can look upon certain milch breeds 'as having affinities with this type, which is represented in Africa by the Afrikander'. The breeds mentioned include the *Sahiwal* and possibly the *Sindhi*, and if these breeds do have Lateral-horned-Zebu affinities this may account for the low fat content of the Mpwapwa Indo-African Zebu crosses as compared with local Shorthorned Zebus.

It is regrettable that descriptions of Indian cattle humps appear to be very rare in the literature and it would seem highly desirable that more should be made available, as thereby light might be thrown on the origin of the musculo-fatty hump of the East African Shorthorned Zebu and on the relation of these cattle with the cattle of India.

Acknowledgements.—I am greatly indebted to Mr. Titus Lwebandiza,

FIG. 1. East African Shorthorned Zebu (Tanganyika)

FIG. 2. Ankole (Tanganyika)

FIG. 5. Shorthorned Zebu. Dissection showing M. trapezius
C = M. trapezius cervicalis. T = M. trapezius thoracalis

FIG. 6. Shorthorned Zebu. Dissection showing hump with M. trapezius removed

FIG. 7. Shorthorned Zebu. Longitudinal section of hump showing its

FIG. 8. Shorthorned Zebu. Foetus (7 months) showing well-marked hump. (Skin has been removed)

FIG. 9. Ankole. Dissection showing hump with M. trapezius removed
L = Ligamentous insertion on to scapula

who has assisted me in making several dissections. I am also grateful to my colleagues Mr. John Robson and Mr. H. J. van Rensburg, who took the photographs of my dissections.

The Public Relations Officer, Dar-es-Salaam, has kindly allowed me to reproduce the photograph of an *Ankole* bull, and finally the Director of Veterinary Services, Tanganyika, is thanked for permission to publish this paper.

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(*Received 27 May 1955*)

EXPERIMENTS ON TOBACCO-SEED PRODUCTION

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VERY little has been published on the effect of cultural practices on tobacco-seed production. Garner [1] stated that reducing the number of capsules by pruning increased the weight of the seeds but did not necessarily improve their quality, and that the leaves of seed plants may be harvested without serious injury to the developing seed if the leaves are not taken too far in advance of the ripening of the seed. Perucci [2] showed the favourable influence of potassic fertilizers as evinced by the greater yield and heavier seed produced.

It is standard practice in most countries, when producing tobacco seed in bulk, to prevent cross-pollination by isolating each variety from all other tobacco by a distance of at least 440 yards. Under such conditions the seed heads are not bagged. In an attempt to improve the quality of seed and to obtain the maximum cash return per acre, some of the lower seed branches are often removed and the leaf is reaped, cured, and sold. Experiments have been conducted during the past three seasons to evaluate the effect of these and other practices in Southern Rhodesia.

Experimental Material and Methods

At the Trelawney Tobacco Research Station, in the 1951–2 season, the effect of 'reaping' and 'trimming' on the yield and quality of seed produced was investigated. The randomized-blocks design had four replications; the variety was Bonanza.

Where seed heads were 'trimmed', only the central inflorescence and two branches below were left and all leaf was removed above the normal topping level. This was done before any flowers opened. 'Reaping' consisted of removing groups of leaves as they matured sufficiently for normal curing. All seed was dried at 85–90° F. in a curing barn, and after threshing it was blown at a standard setting of the seed cleaner, to remove light seed and chaff (approximately 25 per cent. by weight of the threshed seed).

In the 1952–3 season the scope of the experiment was extended to embrace the application of different amounts of fertilizer, including magnesia, and to examine the effect of plant spacing. These factors, together with three reaping and trimming treatments, were combined into a single replicate of a $3^3 \times 2$ factorial layout, in which second-order interactions were confounded to give three blocks of eighteen plots each, with 26 degrees of freedom for error. The variety was C. 7, a derivative of Bonanza × Jamaica Wrapper.

The effects of various levels of nitrogen, phosphate, potash, and magnesia were investigated in the 1953–4 season at the Kutsaga Tobacco Research Station, together with the effect of reaping the leaf. The design was a single replicate of a 3×2^4 factorial layout with certain three-factor

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

interactions confounded to give four blocks of twelve plots each, with 14 degrees of freedom for error. The two-factor interaction Mg × reaping was also partially confounded. The variety was Hicks.

Nitrogen, phosphate, potash, and magnesia were supplied in the 1953–4 season as a mixture of sulphate of ammonia and nitrate of soda in equal parts, superphosphate, muriate and sulphate of potash (1 : 3 mixture), and magnesium sulphate. The mixture used in 1952–3 was essentially the same. Rates of application are shown in Tables 2 and 3.

Results and Discussion

Table 1 shows the effects of different combinations of trimming and reaping on seed production for the three seasons. Crop values given for seed and also for any leaf reaped are assessed on the approximate current market value of each; the price allotted to seed is 10 shillings per ounce.

TABLE 1. *Effect of Trimming and Reaping on Seed Production*

	1951–2			*1952–3*			*1953–4*		
	Viable seed	*Crop value £/acre*		*Viable seed*	*Crop value £/acre*		*Viable seed*	*Crop Value £/acre*	
Treatment	*lb./acre*	*seed*	*leaf*	*lb./acre*	*seed*	*leaf*	*lb./acre*	*seed*	*leaf*
Not trimmed, not reaped	301	2,408	..	192	1,536	..	374	2,992	..
Not trimmed, reaped	210	1,680	250	..	..	..	319	2,552	139
Trimmed, not reaped	226	1,808	..	140	1,120	..	..	..	..
Trimmed, reaped	141	1,128	259	117	936	113	..	..	..
S.E.	±5·9	±45		±8·3	±65		±14·2	±113	

Trimming significantly reduced the seed yield by about 27 per cent. and the value of the crop by about 26 per cent. Reaping the leaf also reduced the yield of seed significantly in 1951–2 and 1953–4, and non-significantly in 1952–3, the value of the cured leaf obtained in no way compensating for the reduction in value of the seed crop. The germination percentage of cleaned seed remained unchanged. Trimming and reaping may, therefore, be considered detrimental.

Tables 2 and 3 summarize the effects of the other factors during two seasons.

Increasing the number of plants per acre slightly reduced the yield of seed per acre and much reduced the yield of seed per plant.

Recent work in Southern Rhodesia [3] has shown the necessity for supplying 100 lb. per acre of phosphate and of potash to all tobacco-leaf crops. In these experiments, seed yield was not increased by applications heavier than this. There was, however, a marked improvement in yield of seed from applications of nitrogen some two or three times as heavy as the rates required for the leaf crop. The seed yield was significantly increased with rates of nitrogen up to 60 lb. per acre; there was a smaller

non-significant further increase with nitrogen applications greater than this amount. Sixty pounds per acre is indicated as the rate likely to be the most economical and efficient for the type of soil on which the experiments were carried out (a coarse sand derived from granite). It is not necessarily the optimum for other soil types, on which the rate required

TABLE 2. *Effect of Spacing and Fertilizers on Seed Production (1952–3)*

Treatment	*Viable seed lb./acre*	
Spacing:		
3 ft. 6 in. × 2 ft.	160	S.E. ± 8·3
3 ft. 6 in. × 1 ft. 6 in.	150	
3 ft. 6 in. × 1 ft.	139	
Fertilizer in lb./acre:		
30 N : 65 P_2O_5 : 40 K_2O	124	S.E. ± 8·3
45 N : 98 P_2O_5 : 60 K_2O	150	
60 N : 130 P_2O_5 : 80 K_2O	173	
MgO:		
None	158	S.E. ± 6·7
25 lb./acre	141	

TABLE 3. *Effect of Fertilizers on Seed Production (1953–4)*

Treatment	*Viable seed lb./acre*		*Crop value £/acre (Seed + leaf)*	
N : 24 lb./acre	258	S.E. ± 17·4	2,158	S.E. ± 138
57 lb./acre	377		3,084	
90 lb./acre	404		3,281	
P_2O_5 : 100 lb./acre	350	S.E. ± 14·2	2,872	S.E. ± 113
200 lb./acre	342		2,810	
K_2O : 100 lb./acre	346	S.E. ± 14·2	2,837	S.E. ± 113
200 lb./acre	347		2,845	
MgO: None	357	S.E. ± 14·2	2,930	S.E. ± 113
30 lb./acre	335		2,752	

will probably be about two or three times the rate necessary for a leaf crop.

With the addition of magnesia there was a non-significantly lower yield in both seasons. Magnesia applications will nevertheless be necessary when magnesium deficiency occurs, a condition frequently found in soils in Southern Rhodesia.

No significant differences were found between the germination percentages of seed from the various treatments. Further analysis of the data from the 1952–3 season revealed a highly significant negative correlation between germination percentage and percentage of threshed seed

remaining after cleaning. Such a negative correlation was also found in the results for the 1953–4 season but did not reach significance. The negative correlation indicates that the small differences which did appear were due to experimental variation. Had real differences in quality existed in the lots of threshed seed obtained from the various treatments, then it would have been expected that cleaning would have removed more from the lighter seed than from the heavier seed of higher germinating capacity, and the correlation would have been positive.

Summary

Experiments on tobacco-seed production over three seasons have shown that trimming seed heads and reaping leaf greatly reduced yield of seed and value of crop with no compensating increase in quality of seed produced. Nitrogen markedly increased seed production; the optimum dressing of nitrogen was 60 lb. per acre. No response in seed yield was obtained by increasing either phosphate or potash applications above 100 lb. per acre. With close spacing and with application of magnesia slightly lower yields of seed were obtained.

Acknowledgement.—The author wishes to thank Mr. D. van der Reyden, formerly Biometrician of the Tobacco Research Board, for advice on layout and design of the experiments and for assistance in the statistical interpretation of results.

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(*Received 23 November 1954; as revised, 30 March 1955*)

THE PERFORMANCES OF FERTILIZER DISTRIBUTORS USED IN FIELD EXPERIMENTS

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THE author previously [1] carried out laboratory tests on three common fertilizer distributor mechanisms to determine whether they were suitable for applying experimental dressings. The factors which caused irregularities in delivery rates were investigated. Later, in a theoretical discussion of fertilizer distributor mechanisms, the author [2] showed that machines fitted with revolving plates or star-wheels were likely to be more reliable than other types. Distributors fitted with these mechanisms have been used recently in experimental field work and their suitability for dispensing different kinds of granular and powder fertilizers was assessed. The purpose of this paper is to summarize the information obtained and to provide some guidance for experimenters using similar machines.

Description of the Tests

Both machines were commercial models in good working order; they were tested without any modification. The star-wheel mechanism was fitted in a combined seed-and-fertilizer grain drill. The revolving-plate machine was a broadcast distributor; fertilizer was dispensed from the plates by 'flickers' rotating on a high-speed shaft.

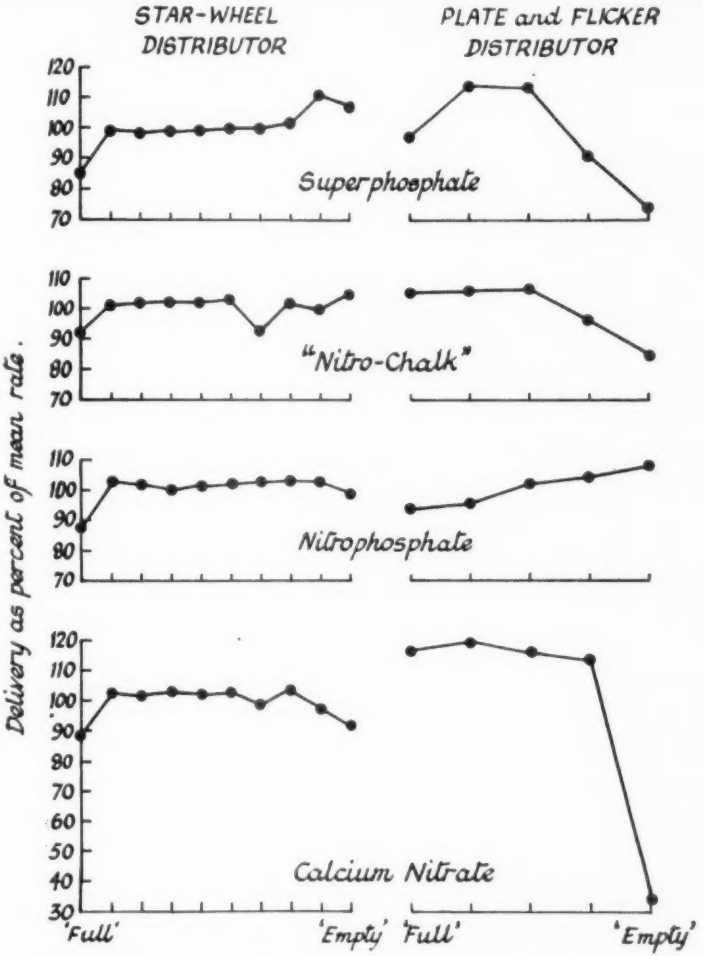
The fertilizers used were commercial materials taken from sealed packages; all the batches were passed through a ¼-in. screen before being used. The granular fertilizers tested were superphosphate, 'Nitro-Chalk' (a mixture of ammonium nitrate and calcium carbonate), nitrophosphate, and calcium nitrate. The nitrophosphate was prepared by the process described by d'Leny [3]; it was included in the tests since products of this type are new to British agriculture and their physical behaviour in distributors had not been studied previously. Calcium nitrate (a commercial Continental product containing 15·5 per cent. N) was tested because it is very hygroscopic and was expected to perform badly in the machines. During the tests the relative humidity varied from 60 to 70 per cent.; under these conditions only calcium nitrate became sticky from absorption of water. The size distributions of the four granular fertilizers are given in Table 1.

TABLE 1. *Size Distribution of Granular Fertilizers used in Tests on Distributors*

	Percentage of material in range					
	over 5 mm.	*3–5 mm.*	*2–3 mm.*	*1–2 mm.*	*0·5–1·0 mm.*	*Less than 0·5 mm.*
Superphosphate . .	1	20	44	31	2	3
'Nitro-Chalk' . .	0	45	26	24	6	0
Nitrophosphate . .	0	38	34	24	2	3
Calcium nitrate . .	2	34	34	16	6	8

[Empire Journ. of Exper. Agric., Vol. 23, Nos. 91–92, 1955]

The 'powder' fertilizers were ordinary commercial products. The ammonium sulphate was in the form of fine crystals; the superphosphate was a rather sticky powder. Ground rock phosphate and dicalcium

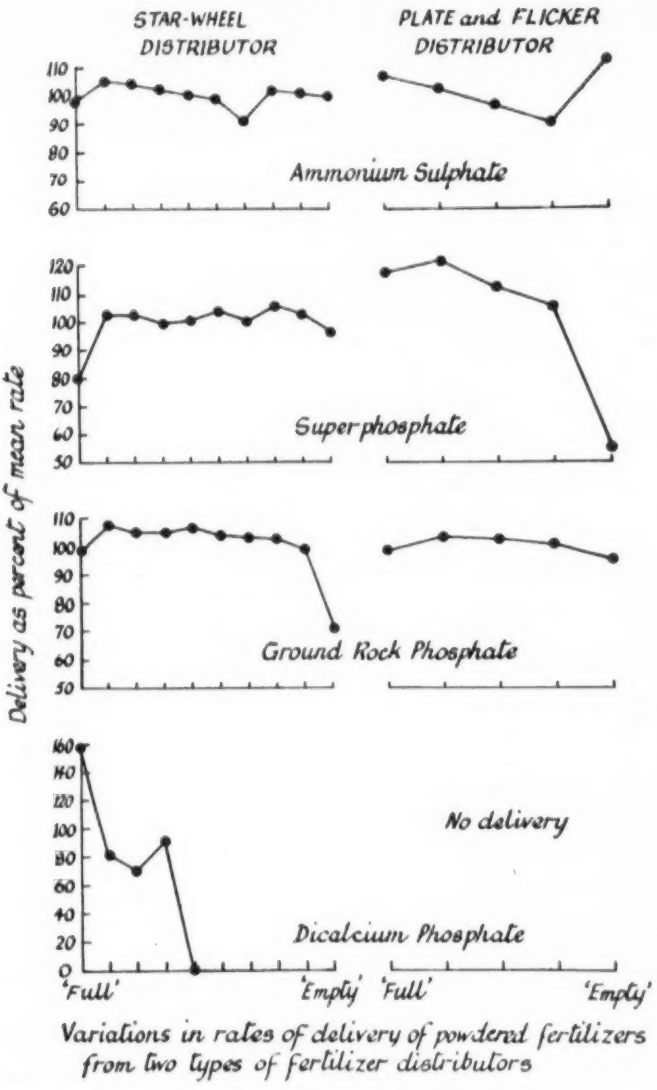


Variations in rates of delivery of granular fertilizers from two types of fertilizer distributors

FIG. 1

phosphate were both very fine powders, practically all passing the 100-mesh sieve. Rock phosphate has a very high bulk-density; dicalcium phosphate is much lighter and does not flow well.

The tests were carried out by filling the distributor hoppers to about



Variations in rates of delivery of powdered fertilizers from two types of fertilizer distributors

FIG. 2

four-fifths of their maximum capacity (designated as 'full' in Fig. 1 and Fig. 2). The mechanisms were set at about three-quarters of the maximum delivery rate indicated by the charts provided by the makers; they were set to deliver these fairly high rates since irregularities are generally more marked under these conditions.

The machines were drawn successive distances of 44 yards until the hoppers were empty. The fertilizer delivered during each 44-yard run was collected and weighed at regular intervals while the hoppers were being discharged; ten measurements were made in each test on the star-wheel machine and five in each test on the revolving-plate distributor. The tests were concluded as soon as any part of the mechanism at the bottom of the hopper was exposed (this stage was designated 'empty').

Results

The results of the tests are stated in Fig. 1 and Fig. 2 by expressing the amounts of fertilizer delivered in successive calibration runs as percentages of the mean recorded delivery rates which are stated in Table 2.

TABLE 2. *Mean Rates of Delivery of Several Fertilizers from Two Distributors*

	Delivery rates in lb./acre	
	Star-wheel distributor	*'Plate-and-flicker' distributor*
Granular fertilizers		
Superphosphate . .	606	1,232
'Nitro-Chalk' . .	635	1,926
Nitrophosphate . .	650	1,456
Calcium nitrate . .	568	1,758
'Powder fertilizers'		
Ammonium sulphate .	539	1,680
Superphosphate . .	460	591
Rock phosphate . .	695	1,299
Dicalcium phosphate .	123	0

All granular fertilizers were delivered by the star-wheel distributor at rather similar rates. There were much greater variations in average rates of delivery of these materials from the 'plate and flicker' distributor, due partly to different bulk densities of the fertilizers, but also to differences in their flow properties. There were large variations in rates of delivery of the four 'powder' fertilizers; very little dicalcium phosphate was delivered by the star-wheel machine and none at all by the revolving-plate distributor.

The star-wheel machine behaved well in the tests and, for practical purposes, its performance was judged to be satisfactory. There were excessive clearances between moving parts in the revolving-plate distributor; when the hopper was filled with granular fertilizers or with ammonium sulphate, a small quantity of fertilizer flowed continuously through the mechanism even when the machine was stationary.

The star-wheel machine delivered all granular fertilizers according to a regular pattern (Fig. 1). The rate rose initially while the first tenth of the hopper capacity was delivered and then remained steady, with minor fluctuations, until practically all the fertilizer was discharged.

The revolving-plate machine was more erratic. Delivery of granular

superphosphate rose to a maximum rate and then fell rapidly. After 'Nitro-Chalk' and calcium nitrate had been delivered regularly from four-fifths of the total hopper capacity, the rates fell away rapidly while the last fifth was discharged. In contrast the rate of delivery of nitrophosphate rose steadily as the hopper emptied. Irregular delivery of granular superphosphate was probably due to the smaller size of the granules. Only one-fifth of the superphosphate was in granules larger than 3 mm.; at least one-third of each of the other granular fertilizers was retained on the 3-mm. sieve (Table 1).

Delivery of ammonium sulphate, powdered superphosphate, and ground rock phosphate from the star-wheel distributor was fairly satisfactory. Generally delivery rose initially, fluctuated a little during the bulk of the test, and decreased noticeably at the end. Dicalcium phosphate was delivered at a low average rate and delivery stopped completely when the hopper was still more than half full, due to blockages of the delivery ports under the star-wheel.

The revolving-plate machine did not deliver any dicalcium phosphate as the fertilizer would not 'flow' down in the hopper on to the revolving plate. Ammonium sulphate and ground rock phosphate were delivered fairly regularly throughout the test of the plate machine, but delivery rates of powdered superphosphate fell seriously in the later stages.

Discussion

Suitable commercial distributors can be used to apply fertilizers with the accuracy needed in most experimental field work provided certain precautions are taken. The fertilizer used should be dry and in good condition. Even hygroscopic materials such as calcium nitrate may be distributed satisfactorily provided they are packed in sealed, moisture-proof bags. Granular fertilizers were delivered more regularly than powders by both machines. Wherever possible granular materials should be chosen if fertilizers are to be spread mechanically.

The star-wheel distributor gave more even rates of delivery than the revolving-plate machine in most of the tests. This was due to the more precise and positive nature of the dispensing action of the star-wheel. The revolving plate machine was built with excessive clearances between the revolving plate and the adjustable 'gate' used to control delivery rates. Commercial 'plate-and-flicker' machines are usually designed so that the plates revolve at a constant slow speed and delivery is adjusted by varying the gate-opening above the plate. Delivery per revolution from a plate machine is independent of plate speed over a wide range [1]. It is more satisfactory to use a small fixed-gate opening (which eliminates unrestricted gravity flow) and to adjust delivery by varying the plate speed, than to use an adjustable gate. If revolving-plate machines are used for experimental work the gate opening should be standardized and set permanently, and a suitable gear-box should be fitted to control the rate of delivery.

In experimental work it is most important that the fertilizer distributors used should be generally reliable and that they should deliver at a steady and reproducible rate through the greater part of their range.

Figs. 1 and 2 show that it is important to reject the initial delivery of most fertilizers from both machines. Either machine should be used so that the first tenth of its capacity is spread over non-experimental land. To secure uniform delivery, the hopper must also be refilled when four-fifths of its total contents have been discharged and some time before any part of the dispensing mechanism is exposed.

If drills proposed for use in experiments are tested the likely variations in delivery rate may be estimated. The effects of such variations on yields depend on the crop and the kind and amount of fertilizer used. When small dressings are used on sensitive crops variations in delivery may cause sizeable percentage changes in the response to fertilizer and so reduce the precision of the experiments. If dressings near to optimum are used, small variations in delivery may have little effect on yields or on the accuracy of the experiments. The effects of variations in fertilizer dressings on the size of crop responses may be estimated from standard data (such as those given by Crowther and Yates [4]). By setting some limits of tolerance for variations in rate of fertilizer application it is possible to decide whether the proposed equipment is suitable, or whether its use may lead to serious experimental error.

For example, the limit of tolerance in delivery rate, under the conditions of the tests described here, may be set at ± 10 per cent. of the average delivery determined by calibrations. Inspection of Fig. 1 shows that the star-wheel distributor would dispense all four granular fertilizers with the desired accuracy. The 'plate-and-flicker' machine would not be suitable for spreading granular superphosphate of the kind used in these tests, but would serve to spread 'Nitro-Chalk', nitrophosphate, and calcium nitrate provided that it was not used after three-quarters of the fertilizer capacity of the hopper had been dispensed. Fig. 2 shows that both machines would distribute ammonium sulphate, powdered superphosphate, and ground rock phosphate within the desired limits of accuracy provided that the initial delivery from the star-wheel machine was rejected and that the machines were refilled when most of the fertilizer had been delivered. It must be emphasized that such decisions on the suitability of equipment can only be taken after making actual field tests with the distributors and fertilizers which are to be used.

Summary

The performances of two commercial fertilizer distributors in spreading powdered and granular fertilizers were compared with special reference to the use of such machines in experimental field work.

A combine-drill fitted with a star-wheel mechanism consistently delivered fertilizers more regularly than a 'plate-and-flicker' mechanism fitted to a broadcast distributor. Granular fertilizers were delivered more regularly than powders. Both distributors were useless for dispensing a very fine and light powdered fertilizer (dicalcium phosphate) which did not flow by gravity. When such commercial machines are used the initial delivery should be rejected and the hopper should be refilled when three-quarters of the fertilizer has been dispensed.

The star-wheel machine delivered four granular fertilizers at rates

which did not vary by more than ±10 per cent. of the average rate; the revolving-plate distributor was equally successful with three of the four granular materials. Both distributors dispensed three powdered fertilizers within these limits of variation.

Likely variations in delivery rate may be estimated by testing the performance of distributors in the field. The effect of such variations on crop yields, and therefore on the accuracy of the experiments, may be estimated by studying the responses of the crops to the fertilizers under test. By setting limits of tolerance in fertilizer delivery rates the suitability of machines for particular purposes may be estimated.

Acknowledgement.—Acknowledgement is made to F. D. Cowland for carrying out the field work with the distributors.

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(*Received 20 July 1955*)

FODDER-BEET FOR FATTENING DUCKS

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IN recent years considerable interest has been shown in fodder-beet; a relatively new crop in Great Britain. Fodder-beet can produce a large weight of dry-matter and soluble carbohydrate per acre [1, 2], and is a useful food for both pigs [3, 4] and cattle [5, 6]. Although classed as a bulky food, fodder-beet is greatly superior to mangolds as a supplementary food for pigs, provided that it is fed in conjunction with a properly balanced meal [3]. This is attributable to the much higher dry-matter content of the fodder-beet compared with that of the mangold [1, 2]. Wartime research in poultry nutrition had indicated that steamed potatoes, swedes, and mangolds were useful substitutes for meal in the rations of ducks [7], but no reference was made to fodder-beet which at that date was virtually an unknown crop in Great Britain. In an experiment with Khaki Campbell ducks [8] the replacement of $\frac{3}{4}$ oz. of mash by $7\frac{1}{4}$ oz. of swedes or $9\frac{3}{4}$ oz. of mangolds had no significant effects on egg-production, but resulted in losses in body-weight. This suggested that the ration was not adequate to cover both the maintenance of body-weight and the requirements of egg-production. Later work [9] on the value of potatoes as a food for ducks directed the authors' interest towards the possibility of substituting a portion of the meal ration of fattening ducks by fodder-beet. A series of feeding trials with this relatively new crop were thus carried out and are reported in this paper.

Experimental Design and Methods

Six main experiments were conducted; four in the spring and summer of 1953 and two in the late spring of 1954. A preliminary trial had shown that the fodder-beet could be fed to ducklings at an age of 3 weeks and that it was palatable.

In each experiment Aylesbury ducklings were used and all the birds were of similar breeding. The birds were sexed immediately after hatching and only the males used. This was considered necessary in order to eliminate the difference in weight known to occur owing to sex: drakes are invariably heavier than similarly reared ducks of the same age [10]. The birds were then wing-banded and weighed. Each batch of ducklings was reared under an electrically heated brooder, and, as they became older, a larger area of open run was allowed. Up to three weeks of age the birds were fed thrice daily on a commercial chick-rearing meal containing 22·8 per cent. crude protein in the dry-matter and always had access to clean drinking water. When three weeks old, the ducks were divided into two groups containing equal numbers. The number was normally twelve, although in experiments 1 and 3 ten and eleven birds respectively were used. This was because no bird under a weight of

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400 g. at 3 weeks of age was allowed in the experiment. The two groups of ducks were then housed and managed under identical conditions apart from the different rations. In experiments 1 and 2, after 3 weeks of age the ducks were housed in movable huts on old pasture and moved daily. In the remainder of the trials they were housed indoors on peat

TABLE 1. *Composition (as per cent. of total) of Meals A and B*

	Meal A (control)	*Meal B (fed with the fodder-beet)*
Fine wheatings	34·0	29·0
Barley meal	30·0	24·0
Maize meal	20·0	15·0
White fish meal	10·0	20·0
Dried yeast	2·0	4·0
Dried lucerne meal	2·0	4·0
Bone meal	1·0	2·0
Ground limestone	0·25	0·5
Salt	0·25	0·5
'Nuclo'*	0·50	1·0

* Vitamin supplement containing 800 I.U. Vitamin A and 100 B.S.I. units Vitamin D_3 per g.

moss throughout in an effort to ensure even greater uniformity in environmental conditions. Artificial heat was discontinued at 4 to 5 weeks of age, depending on the weather.

The two feeding treatments were as follows. Group A, the control

TABLE 2. *Chemical Composition of Meals A and B, and the Fodder-beet*

Per cent. of food	*Meal*		*Fodder-beet*	
	A	*B*	*1952/3*	*1953/4*
Dry matter	87·3	87·7	22·30	20·00
Crude protein	18·7	25·6	0·96	1·00
Ether extract	3·1	2·5	0·03	0·04
Soluble carbohydrates	52·8	44·9	19·48	17·28
Crude fibre	5·5	5·0	0·98	0·88
Total ash	7·2	9·7	0·85	0·80
Silica-free ash	..	..	0·71	..
Calcium (CaO)	1·9	3·1	0·05	..
Phosphate (P_2O_5)	2·9	3·8	0·06	..

group, was fed an all-meal ration (Meal A) the entire period from 3 to 9 weeks of age. The constituents of this meal and its chemical composition are given in Tables 1 and 2 respectively. The meal was fed as a mash thrice daily in amounts that were cleared up by the time of the next feed. Group B received a basal daily ration of 126 g. (4·5 oz.) meal B and fodder-beet to appetite. Details of meal B are also given in Tables 1 and 2. The composition of this meal was a much simplified version of one used by Heuser, Scott, Eskew, and Edwards [11] in trials on the sub-

stitution of potatoes in duck rations. The dried brewer's yeast was included in view of the work of Heuser and Scott [12] on bowed legs in ducks.

The variety of fodder-beet was Pajbjerg Rex X which had been grown on adjacent plots in the same field under similar conditions in both 1952 and 1953. After harvesting it was stored in a straw-covered clamp until required. Before feeding, the beet was cleaned of any loose soil and sprouts, fingered in a cattle root-chopping machine, and finally chopped into small pieces by a hand-operated Proctor mincer and shredder. The chemical composition of the fodder-beet is given in Table 2.

All food and refusals were weighed at each feed. Refusals were in fact negligible. The ducks always had access to clean drinking water and were weighed weekly.

The ducks were killed when exactly 9 weeks old, no food having been fed on that morning. The exact procedure followed in each experiment was to weigh the duck alive, kill and pluck it within 15 minutes, and finally weigh the carcass plus heart, liver, and crop, but minus head, legs, and alimentary tract, whilst still warm. This weight expressed as a percentage of the live weight has been termed the 'killing-out percentage' (Table 3) of the bird. The carcasses were then placed in a refrigerator until cooked and tasted.

Results

Throughout the six experiments all the ducks were in good health and no birds were lost either from disease or accident. Growth rates of individual birds within experiments were consistent and the summarized

TABLE 3. *Average Live-weight Gains (g.) per Duck from 3 to 9 weeks of Age and Killing-out Percentage of the Birds*

		Live-weight gain		*Killing-out percentage*	
Number of experiment	*Date experiment commenced*	*Group A All-meal (control)*	*Group B Meal-plus fodder-beet*	*Group A*	*Group B*
1	17.3.53	1,458	1,532	68·7	69·2
2	21.4.53	1,533	1,311	68·2	67·8
3	26.5.53	1,783	1,583	71·7	68·9
4	30.6.53	1,943	1,540	72·1	72·1
5	30.4.54	1,724	1,393	69·2	66·8
6	25.5.54	1,582	1,441	68·3	67·9
Mean		1,671	1,467	69·7	68·8
Standard error of mean		±48		±0·4	

data of live-weight gains in each experiment are given in Table 3. Apart from experiment 1, it will be seen that the ducks in group A always had a superior live-weight gain compared with those in group B. The difference was particularly large in experiments 4 and 5. On average, over the six experiments, the all-meal-fed ducks gained 12 per cent. more than

the meal-and-fodder-beet-fed birds: a difference significant at the 5 per cent. level. In 1953 the all-meal-fed ducks showed increasing live-weight gains in successive experiments, but no such trend was recorded in the beet-fed birds. Insufficient experiments were conducted in 1954 to justify comment on this factor.

As an indication of the quality of the ducks in the two groups, details of the killing-out percentages of the birds are also given in Table 3. On average the all-meal birds had a slightly higher value than the beet-fed ducks, but the difference between the means of the two groups was not significant ($P>0.05$). The variation in the killing-out percentages throughout the experiments was not wide, and, as with the live-weight gains, they showed a tendency to increase in successive experiments in 1953. This was evident in both the all-meal and fodder-beet-fed groups.

TABLE 4. *Average Consumption of Meal per 1 g. of Live-weight Gain, and Percentage saving in Meal Consumption*

	Weight of meal (g.) per 1 g. of live-weight gain		
Number of experiment	*Group A All-meal (control)*	*Group B Meal plus fodder-beet*	*Percentage saving in meal consumption*
1	6·60	3·45	45
2	6·63	3·90	50
3	5·38	3·08	49
4	6·12	3·44	55
5	6·46	3·74	53
6	6·37	3·58	49
Mean	6·26	3·53	50

The weight of meal consumed per g. of live-weight increase for the two groups and the economy effected by feeding the fodder-beet are shown in Table 4. On average the all-meal birds ate 6·26 g. of meal per 1 g. of live-weight gain, whereas the beet-fed ones ate only 3·53 g. By calculating the consumption of meal per unit of live-weight increase the beet-fed birds showed a saving of 44 per cent. of meal compared with the all-meal group. The saving of meal in each experiment without considering differences in live-weight gains (Table 4, column 4) ranges from 45 to 55 per cent. with a mean value of 50 per cent. From the results of the six trials it is calculated that 1 g. of meal was replaced by 2·98 g. of fodder-beet.

No obvious differences in the quality of the flesh or fat of the ducks in the two groups were apparent by handling or by visual assessment of colour or texture.

It took approximately the same time to pluck and dress the birds in both groups, but it was observed repeatedly that the beet-fed ducks had dirtier feathers than the all-meal birds and that their bedding was messier. No difference in the cooking quality or palatability of the ducks was detected.

Discussion

These experiments indicated quite clearly that fodder-beet with a dry-matter content of 20 to 22 per cent. was a highly palatable food for ducks: birds only three weeks of age consumed it eagerly. Wright and Dudley [8] experienced no difficulty in getting ducks to eat bulky rations containing steamed roots, and, as in the above experiments, the health of the birds remained good throughout. It is of interest to note that the fodder-beet grown and harvested in 1952 was fed as late as August 1953. Fodder-beet will normally store well up to this date [13] and will even remain practically unchanged in the soil under winter conditions (Castle, [14]). The feeding of fodder-beet could therefore be extended over a large part of the year if required.

The outstanding value of the use of fodder-beet in the diet of ducks is in the saving of meal. By feeding the fodder-beet a saving of 50 per cent. of the total weight of meal was made. This is an economy which in periods of a shortage of meal, e.g. in war-time, would be more striking than at the present time. Potato meal has been fed to ducks and has effected similar economies [7], but it must be remembered that fodder-beet requires no cooking and that the yield of dry-matter per acre from fodder-beet is invariably higher than that from a crop of potatoes grown under similar conditions. If the economy of meal is calculated on a stricter basis, i.e. per unit of equal live-weight increase in the two groups of ducks, the saving of meal is still 46 per cent., a substantial value. These values are very similar to those quoted by Braude and Mitchell [3] in experiments on the feeding of fodder-beet to fattening pigs. No adverse effects on the quality of the carcasses as a result of feeding the beet were found, and, as shown in Table 3, the killing-out percentages were very similar. On the score of quality, the fodder-beet can be considered as a suitable food for inclusion in the diet of fattening ducks.

Fodder-beet is essentially a carbohydrate food, and, as can be seen from the chemical analysis in Table 2, has a low crude-protein, ether-extract, and mineral content. The basal meal B was therefore designed to rectify these deficiencies when fed with the fodder-beet. However, the beet-fed ducks did not increase in live weight as rapidly as the ducks on the all-meal diet. A possible reason for this is that on the average they ate only 2·98 g. of fodder-beet to replace each 1 g. of meal removed from their ration. At this rate of substitution the two diets contained practically the same weight of soluble carbohydrate, but the fodder-beet group were receiving less crude protein and minerals. For both groups of ducks to receive an equal weight of all nutrients more fodder-beet should have been consumed. The appetites of the ducks were probably satisfied with the bulky diet of fodder-beet and it might possibly have been advantageous to feed a larger weight of basal meal to the fodder-beet group. The saving of meal might not have been so great but better live-weight gains might have resulted.

Exact costings were not kept during these experiments and further trials on a larger scale are necessary to answer this question fully. Home-grown fodder-beet is normally cheaper per unit of dry-matter

than a purchased carbohydrate meal, but to offset this saving a more expensive basal meal must be fed with it, and there is also the expense of handling and chopping the beet. Fodder-beet can usefully replace meal in the rations of fattening ducks, but the extent to which it is used must depend ultimately on prevailing economic conditions.

Summary

1. Details are given of six feeding trials with fattening Aylesbury ducks to investigate the feeding-value of fodder-beet.

2. Group A, a control group, were fed with meal only; Group B were fed with a basal daily ration of 126 g. (4·5 oz.) of high-protein meal, and fodder-beet to appetite.

3. The fodder-beet was very palatable.

4. The average gain in weight from three to nine weeks of age of Group A was 1,671 g. and of Group B 1,467 g.

5. The average killing-out percentages of groups A and B were 69·7 and 68·8 respectively.

6. The saving of meal in group B compared with group A was 50 per cent., and 1 g. of meal was replaced by 2·98 g. of fodder-beet.

7. The feeding of fodder-beet to ducks is discussed.

Acknowledgements.—The authors wish to thank Mr. J. Featherstone, Nutrition Chemist, West Midland Province, National Agricultural Advisory Service, for the analysis of the samples, and Miss J. Ashcroft for her valuable assistance in rearing and feeding the ducks.

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(*Received 6 April 1955*)

LETHAL YELLOWING: THE 'UNKNOWN DISEASE' OF COCONUT PALMS IN JAMAICA

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With Plates 11, 12, and 13

IN parts of certain islands of the Caribbean a serious disease has brought cultivation of coconut palms virtually to an end. In Jamaica, for example, very few plantations remain in the western third of the island. There are reliable reports of the occurrence of this disease outside Jamaica, in the Cayman Islands, Haiti, the Bahamas [1], and possibly also in Cuba [2]. Its distribution elsewhere is uncertain because the disease was formerly confused with bronze-leaf wilt; it has also been known as 'bud-rot', 'west-end bud-rot', and, more recently, as the 'unknown disease'.

The disease is not of recent occurrence, but concern was first caused in Jamaica only after the establishment of large plantations. In Martyn's comprehensive historical survey [3] he referred to it as bronze-leaf wilt, a disease now known not to have been found in Jamaica. From this account, largely derived from Johnston [4], it appears that Fawcett observed it in Grand Cayman in 1889 and assumed that it was the same as that noticed there by the Marquis of Sligo in 1834. Fawcett also reported its occurrence in Montego Bay (Jamaica) in 1891, and showed that it was well established on the north coast by 1902. Relatively few coconut palms were grown there at that time, but comment was made on the careful precautions taken by planters to check the spread of 'bud-rot diseases'.

Ashby [5] described the disease and called it 'west-end bud-rot', to distinguish it from the common bud-rot of coconut palms caused by *Phytopthora palmivora* and to indicate its restriction to the western part of Jamaica.

Martyn [3] stated that in 1934, after hurricanes in the previous two years, 'bronze-leaf wilt' began to cause considerable damage and to destroy many plantations along the north-west coast. As a result of a statement by Bain [6] that the west-end bud-rot of Jamaica was the same disease as the bronze-leaf wilt of Trinidad and was attributable to soil conditions, the policy of destroying diseased palms had been largely abandoned. Martyn, however, strongly recommended the resumption of control measures, and after lengthy investigations he concluded that no trace-element deficiency was responsible nor, indeed, any other soil factor. Although this worker found no causal organism, he always considered the disease to be pathogenic, and, in spite of his failure to transmit it mechanically, he suggested that its cause might be a virus.

Leach [1], after a detailed field study, came to no conclusion as to whether the disease was pathogenic. He observed that it was most serious in conditions favouring vigorous growth, and suggested that soil conditions were correlated with incidence through their effect on the

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nutrient status of the tree. He drew attention to the differences between bronze-leaf wilt and the Jamaican disease and, as a consequence, referred to the latter as 'an unknown disease of coconut palms'. Since then this expression has, regrettably, become widely adopted as a name. Investigations by Innes [7] discounted the possibility that a deficiency or excess of manganese or any other mineral, or any other soil condition, could be concerned.

Hansen [8] failed to isolate any fungal or bacterial pathogen, or to effect mechanical transmission, and thereupon dismissed the possibility of a pathogenic cause. He asserted that the disease was the result of strontium poisoning, and postulated the source of the strontium to be submarine deeps, the water from which, after having been brought to the surface by hurricanes, was distributed over the coastal areas of adjacent lands in the form of spray. An alternative hypothesis was the supposed existence of strontium, in an insoluble form, in some Jamaican soils, from which it could be liberated by the action of sea-water, again distributed by hurricanes. These views, however, do not stand critical examination, and cannot be considered seriously.

It is suggested that 'lethal yellowing' is a more suitable name for the disease than 'west-end bud-rot', which has never been widely accepted and has a purely local significance; the name now proposed implies that death always results, which is not the case with bud-rot, and distinguishes between the characteristic intense coloration associated with it, and other common forms of non-lethal, and usually temporary, yellowing.

Symptoms of Lethal Yellowing

These have been described in detail by previous workers and only a summary is given here. The first sign is the premature shedding of nuts of all ages; at the same time the young inflorescences (which are opening at an accelerated rate) develop necroses and finally become dried out and blackened (Plate 12). Shortly after, the lower leaves develop a conspicuous rich yellow colour, which eventually spreads over the whole crown (Plate 11). In the earliest stages of disease sodden patches can be found on the basal parts of the still-folded heart leaves: these patches extend later, and the final result is a widespread and offensive-smelling soft rot of the spike. As a result of the decay at their bases, the young leaves wither at the tips, but the main growing point and the surrounding tissues remain apparently unaffected until a late stage of the disease, in spite of the proximity of the decaying leaf bases. During these developments the roots become progressively disorganized, and few functional ones remain by the time the crown is conspicuously yellow. There is sometimes a tendency for nut fall and root disorganization to be unilateral. All the leaves are eventually shed, the rot extends to the bud and kills it, and the bare trunks are left standing (Plate 11). No cases of permanent recovery have ever been recorded.

Epidemiology

Lethal yellowing is now pandemic in the western part of Jamaica, and few clear indications of its pattern of spread remain. Only an occasional

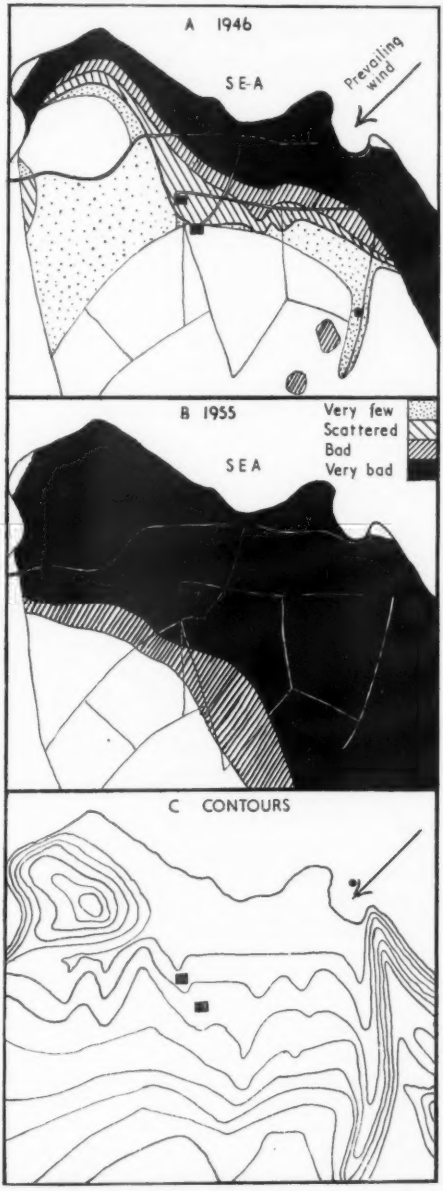


FIG. 1. Sketch-maps of part of the north coast of Jamaica. Each map is approximately a half-mile across.
A. After Leach, showing the disease situation in 1946. B. The disease situation in February 1955. C. Approximate contour map, after Leach.

'island' of mature palms survives, and attempts to map the progress of the disease in one of these showed that its incidence was general. Formerly, however, the situation seems to have been clearer. Thus, 'W.H.', in 1909, wrote of a 'bud-rot' disease (certainly lethal yellowing) which exhibited a 'marked tendency to spread from each centre of infection'. Again, Martyn [9] stated that 6–12 months after the establishment of the disease in one plantation affected palms can be found in the scattered cultivation between it and the next. Later, this too is attacked, at first sporadically on the boundary, but soon building up to epidemic proportions and resulting in complete devastation within a few years. In this manner lethal yellowing has virtually destroyed the coastal belt of plantations, and has encroached deeply inland to hill country, usually following the course of valleys, and into different soil types.

This type of progress is illustrated in Fig. 1, which compares the situation in February 1955 with that published by Leach in 1946; it shows that the disease has advanced considerably, uphill, and in the direction of the prevailing wind. The greater part of this uphill advance has occurred during the last year or so, as the distribution in early 1954 did not differ greatly from that in 1946. The disease has been extremely active since then, however, in the coastal strip, which has been replanted at least four times, the remnants of the last replanting having all died out by the end of 1954.

Pathology

Although previous workers had failed to find a pathogen, another search for a causal fungus or bacterium was undertaken. Trees of all ages, in every stage of the disease, and from different soil types, were studied both histologically and culturally. The roots of five diseased trees, and two healthy ones, were examined *in situ* by digging 4-feet-deep trenches radially from the trunks and washing the soil away from one of the sides with high-pressure water jets. Roots of all other trees studied were sampled by excavation. Even in healthy palms it is usual for roots to die back to a certain extent, the dead tips being replaced by new adventitious ones which arise immediately behind them. This die-back is normal, and the greater part of the root system of a healthy palm remains alive and functional. In affected palms, while root die-back follows the same pattern, it is very much more extensive even in the early stages of the disease, and the death of new adventitious roots is greatly accelerated. Few functional roots remain by the time that yellowing of the crown is noticeable.

The macroscopic appearance of the rotted root tips is similar in healthy and in diseased trees. Environment and soil type determine whether a wet decay results, as in heavy or moist soils, or whether the tips merely die back and dry, as in light or sandy soils. Again, microscopically, there is nothing to distinguish the roots of healthy from those of diseased trees. Fungal hyphae are usually present in moribund roots, and mycorrhizal fungi have sometimes been found in healthy ones; sometimes hyphae are absent. The boundary between the healthy and the necrotic parts is

usually sharp, giving more the impression of an attack by saprophytic organisms on moribund tissues than of an invading parasite.

Isolations were attempted from the roots of a very large number of trees, and, very occasionally, the plated roots remained sterile. Apart from bacteria, and some common tropical soil saprophytes (e.g. species of Fusarium, Botryodiplodia, and Pestalotia), no one fungus was consistently, or even frequently, isolated. Several, which appeared more than once, were established in pure culture and inoculated to developing roots of seedling coconut palms and, in a few experiments, to older roots of young palms in the field. With one exception, none caused more than a slight local reaction close to the inoculation wound, or proved capable of invading uninjured roots. The exception was an unidentified fungus, producing abundant small black sclerotia in culture, which proved to be an active wound parasite of young roots although incapable of attacking uninjured or older ones. Because of this result, however, a search was made for this fungus in association with diseased trees, but it was only isolated on three occasions in all.

In the early stages of the development of the sodden patches in the heart leaves no micro-organisms were found: later, however, these became invaded by saprophytes, mainly bacterial, and a rapid breakdown of the surrounding tissues ensued, culminating in the offensive-smelling soft rot.

By contrast, neither microscopic nor cultural examination of the necroses which develop in the still-sheathed young inflorescences, and beneath the calyxes of the nuts, showed any early evidence of fungal growth; these did become invaded much later, however, by saprophytes, among which species of Fusarium and, occasionally, Phytopthora have been isolated.

Histological examination of the trunks and other parts of affected palms revealed no vascular or other type of parasite, or phloem abnormality: in the cells, however, particularly of the leaves, double and sometimes multiple nuclei were frequent. This point will be referred to later.

To sum up, necroses which developed in areas adequately protected structurally against invasion from outside by micro-organisms, i.e. the young inflorescences and the nut-bases, remained sterile for a long time. Necroses in the heart leaves, being more exposed, were invaded comparatively early but were, at first, sterile. Necroses in the roots, on the other hand, being in contact with the soil, were invaded at a very early stage: even in these, however, sterile necrotic roots have occasionally been found. Thus, none of the necroses, including those of the roots, was primarily associated with fungi or bacteria, and all organisms later found in them were purely saprophytic.

Observations Bearing on the Nature of the Disease

Failure to find any fungal or bacterial pathogen in association with lethal yellowing agrees with the results of previous workers: there is, however, little possibility that the disease could be caused by any soil condition, mineral excess or deficiency. The epidemiology strongly suggests a pathogen, as do all field observations. For example, the

disease occurs on different soil types, on sandy sea shores, in rich river alluvium, and on hills. Moreover, directly comparable conditions exist in the eastern part of Jamaica, where the disease is absent.

These facts suggest that lethal yellowing might be caused by a virus. To verify this hypothesis, however, transmission is essential and this presents difficulties. Grafting is, of course, not possible. It seems unlikely that the disease spreads mechanically in the field, and attempts to achieve experimental mechanical transmission to seedling palms or to possible indicator plants have failed with us as they did with Martyn and with Hansen.

Experimental work cannot be done in the field in the unaffected parts of Jamaica because of the risks of introducing the disease: in the affected parts, on the other hand, where lethal yellowing is pandemic and where all young palms planted in recent years have died at an early age, transmission experiments could not be expected to yield reliable results.

The size of the coconut palm precludes the possibility of work in insect-proof houses, for plants are rarely affected at less than 3 years of age, when they average 20 feet in height, with a frond length of 13 feet. In the absence of any possibility of attempting effective experimental transmission, therefore, evidence which might bear on a virus hypothesis has been sought from other sources.

Cytology

It was observed that many of the cells of diseased palms contained two, or sometimes more, nuclei (Plate 13, Figs. 2 and 3). These occurred mainly in the epidermis and ground tissue of the leaves, but could also be found in the petioles, bases of developing nuts, and sometimes in the roots. They appeared normal, stained with the usual nuclear stains, including Feulgens, and nucleoli could be clearly differentiated with such combinations as methyl green with acid fuchsin.

Affected cells tended to occur in groups or islands of tissue, although occasional isolated ones could be found. Binucleate cells have been found in every diseased plant examined, and also in some still apparently healthy palms in the affected part of Jamaica. For example, in one plantation which, from its age and situation, is almost certain to exhibit disease symptoms soon, leaf samples were taken from twelve trees. Cells with double nuclei were very frequent in one plant, frequent in three, rare in six, and not detected in two. This abnormality does not occur in healthy palms. Double nuclei could not be found in leaves of either mature or seedling palms collected in the unaffected part of Jamaica; they were also absent in leaf samples obtained from Malaya and from Trinidad. Further, the Malayan Dwarf variety of palm, which exhibits marked field resistance to lethal yellowing, has no binucleate cells, even when samples are taken from a plantation where the disease is exceptionally active among the tall variety.

The production of abnormalities in plant cells is commonly associated with some virus diseases, and their presence can be taken as strong evidence that a virus is involved. The occurrence of double nuclei in

this connexion, although less well known than intra- or extra-nuclear inclusions, has been recorded previously. Thus, Sheffield [10] inoculated leaves of *Nicotiana glutinosa* under carefully controlled conditions with aucuba-mosaic virus, and found that nuclear division, unaccompanied by cell-wall formation, was induced after 12–48 hours, resulting in binucleate cells: that this was not a wound reaction, but was directly due to stimulation set up by the virus, was shown by their absence from control leaves rubbed with water or with healthy plant sap. Salaman [11] found that inoculation of tobacco plants with the X^n strain of potato virus X resulted in the production of binucleate cells, while other strains of the same virus produced the usual amorphous type of cell inclusion. Again, Weintraub and Gilpatrick [12] observed that infection of *Dianthus barbatus* with tobacco-ringspot virus gave rise to the production of 'many binucleate cells 5–6 days after inoculation'.

Thus, palms affected with lethal yellowing, a disease of unknown aetiology, exhibit a cytological abnormality which has, so far, been associated only with virus infection, and which has been experimentally produced by the inoculation of other kinds of plants with three known viruses.

Attempted Use of Serological Techniques

An attempt to use serological techniques yielded somewhat anomalous results. The considerable difficulty experienced in expressing sap from coconut leaves was overcome to some extent by using leaflets from still-folded fronds which showed only a trace of green colour, and this might, perhaps, have influenced the results. Two rabbits were injected with partially purified sap [13] from diseased and from healthy plants respectively: as a precaution leaves from healthy plants were obtained from the extreme east of the island.

The antiserum prepared against diseased sap lost activity unusually rapidly. For instance, when freshly prepared, precipitin tests gave two optima at about the 1/5 and 1/160 dilutions. After 2 weeks, only one definite optimum remained, this lying between the 1/80 and the 1/160 dilutions; the results of one of several tests made at that time are shown in Plate 13, Fig. 1. Five weeks later the antiserum had lost all trace of activity. Moreover, in appearance the precipitates conformed neither to the H nor to the O types: they were milky in appearance, remained in suspension for long periods, and when centrifuged down were off-white in colour and seemed slightly gelatinous in texture. Control tests gave no precipitates, whether made with 'healthy' serum against either diseased or healthy plant sap, or with 'diseased' serum against healthy sap.

Thus, anomalous though they are, the results show that coconut palms affected by lethal yellowing contain one, and possibly two, substances capable of acting as antigens, which are absent from healthy palms.

An Attempt to Induce Recovery from Lethal Yellowing

Coconut palms can be transplanted with success, even when of considerable size, and advantage was taken of this to carry out the following experiment. Eighteen young palms, varying from 2 to 4 years old and all

in the early stages of disease, were dug up. All the roots were cut off close to the boles, and these, with the root bases, were washed with high-pressure water jets until all visible traces of soil were removed and were then repeatedly drenched with fungicide. Four healthy control trees were treated in the same way, and all were transplanted into a site on which coconuts were not known to have been grown previously and with no diseased palms in the neighbourhood.

Elimination of affected tissues and adhering soil, combined with the fungicidal treatment, might have induced recovery in some trees at least, if lethal yellowing were caused by a fungal root pathogen. However, the course of the disease was in no way interrupted, and all affected palms died within 3 months: the controls, on the other hand, all survived, and started vigorous growth after a few weeks. As the treatment could not have affected a systemic infection, this result would be expected were the disease caused by a virus. The possibility of a vascular parasite, which would also have been unaffected, had already been eliminated.

Field Indications Bearing on the Nature of the Disease

In Jamaica trade winds blow consistently in one direction and there is a correlation between wind-direction and disease-spread compatible with an hypothesis that lethal yellowing is caused by an insect-transmitted virus. Martyn has recorded that the disease has progressed steadily from east to west, in the direction of the prevailing wind, and this is illustrated for one district in Fig. 1. The same trend was reported for Cayman Brac where, in 1911, the disease first appeared in the centre of the island, and the most rapid spread took place down-wind (Commissioner of the Cayman Islands; in departmental files).

Jamaica is also subject to hurricanes, in the path of which violent air currents could distribute potential vectors widely. The usual course of these hurricanes, however, is westerly and distribution of infective vectors by this means from the west to the east of the island would seem improbable, and, in fact, the disease has remained confined to the west for a very long time (Fig. 2). It is a general and apparently well-founded belief, however, that *locally* both the range and the intensity of the disease increases after hurricanes, and Martyn has recorded that this occurred in 1934 after hurricanes in the two previous years. Another example of a sudden appearance of the disease in a new area, explicable most readily on a theory of wind distribution, is illustrated by Leach's account of its history in Haiti where, after having been confined for many years to one region, in 1943 it suddenly appeared in another region 40 miles away and within 2 years had destroyed practically all of approximately 8,000 bearing palms.

A characteristic of lethal yellowing is that it affects plantations of young trees more severely than mature ones, and vigorously growing palms of any age suffer more severely than those which are affected by an unfavourable environment. It has frequently been noticed that, where whole groups of palms have been attacked by lethal yellowing, often the only survivors are those trees which are affected by 'pencil-point'. Again, both Leach and Hansen remarked on the frequent longer

survival, in devastated plantations, of those palms which had been partially uprooted and thrown to the ground by hurricanes. This behaviour is characteristic of many, if not all, virus diseases, which are well known to affect young plants more severely than older ones, and vigorously growing plants more than those which are, for example, pot-bound or suffering from nutritional deficiencies.

Again, it is usual for virus disease symptoms to be most marked in those parts of the plant which are differentiating most rapidly. In the coconut palm these are the root tips, the developing leaves of the central

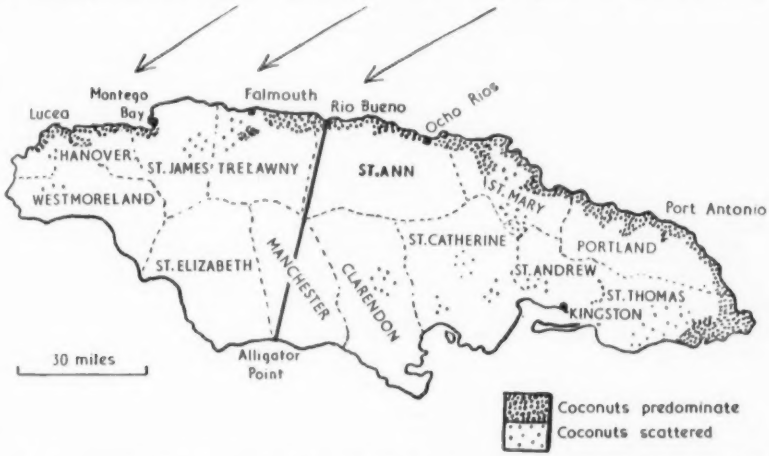


FIG. 2. Sketch-map of Jamaica, showing the approximate boundary between the western affected part of the Island, and the eastern and unaffected part. The main areas of coconut plantations are shown as indicated by Martyn.

spike, the immature inflorescences, and the bases of the young nuts: it is precisely in these regions that the necroses associated with lethal yellowing appear. Localization of attack to such areas, however, is not particularly characteristic of diseases caused by pathogens other than viruses.

These observations, therefore, all tend to support an hypothesis of a virus causation for the disease, and some of them, of a virus transmitted by an insect vector: they imply, too, that this vector is likely to be mainly sedentary. There is no possibility that the disease could be spread by infected pollen, as palms are most susceptible when young, and frequently die before they flower.

Conclusions

Lethal yellowing is almost certainly a pathogenic disease. A considerable weight of negative evidence, as well as some strong positive indications, suggests firstly that a non-virus cause can be discounted, and secondly that a virus is the most likely pathogen: there are difficulties, however, which cannot at present be overcome, in the way of making standard transmission experiments, which alone could confirm this. In

addition, the serological results tend to suggest that there may be more than one virus involved, and some support for this view is found in the extremely lethal character of the disease.

There are two questions of immediate concern to the coconut industry of Jamaica: firstly, whether plantations can be re-established in the devastated areas, and secondly, whether the disease is likely to spread outside its present limits, and, in that event, whether prompt action might contain it.

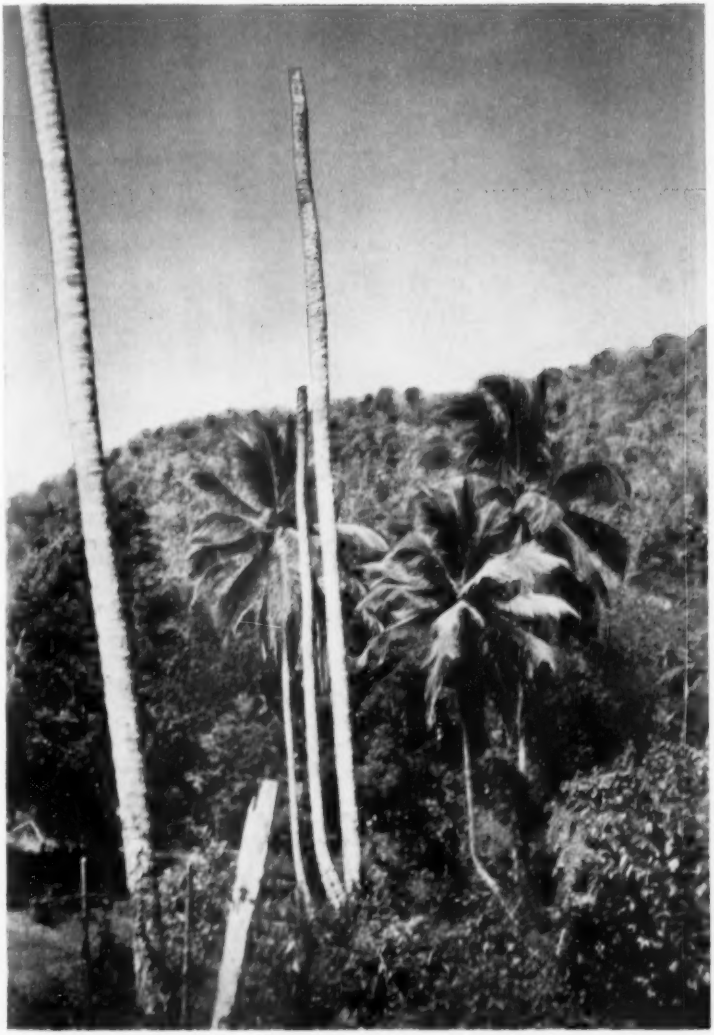
With regard to the first question, there is little prospect that, even if the insect-transmitted-virus hypothesis were fully proved, any economically practicable control measures could be devised with a plant such as the coconut palm, which would permit replanting with susceptible varieties. Re-establishment might be possible, however, with a resistant variety. The spectacular survival of the few plantings of the Malayan Dwarf palm within the devastated areas suggests that such a variety is already available. Although formal field tests have not been made, the supposition that this plant is highly resistant to lethal yellowing is supported by the failure to detect double nuclei in its cells. This variety, however, has certain practical disadvantages, and for this reason it is desirable that other resistant varieties should be sought outside Jamaica.

With regard to the possible future spread of lethal yellowing, its restriction, for many years, to the west of a fairly clearly defined boundary is unlikely to be fortuitous. It may be due partly to the much slower advance of the disease against the prevailing wind, and partly to the discontinuous nature of coconut cultivation in the neighbourhood of the boundary. On the other hand, the control measures which have been taken by the Department of Agriculture over the past decade (the felling of all diseased trees in a belt to the west of the boundary) may have contributed, perhaps largely, to this restriction. The recorded behaviour of the disease in Haiti, and its sudden outbreak in one of the Cayman Islands, however, give no grounds for confidence that the disease may not suddenly appear at any point in the eastern part of the island: in this event prompt and wholesale eradication of all palms in the vicinity of outbreaks would probably be justified.

Summary

Lethal yellowing (formerly called 'west-end bud-rot', 'unknown disease', and sometimes confused with 'bronze-leaf wilt') is a serious disease of coconut palms in the Caribbean area.

Although clearly of pathogenic origin all attempts to find a fungal or bacterial cause have failed. The characteristic necroses produced by the disease appear only in those parts of the plant where rapid growth and differentiation are taking place, and are initially sterile although they eventually become invaded by saprophytes. A virus causation appears likely, but transmission work to prove this is not at present feasible. A virus hypothesis is supported, however, by absence of other pathogens; epidemiological data; the disease symptoms; the occurrence of double nuclei in the cells of affected plants; positive, though anomalous, results



Group of coconut palms showing one tree with late symptoms of lethal yellowing, one in the early stage of the disease and one still apparently healthy. The bare trunks in the foreground are those of trees killed some time previously

FIG. 1. Series of inflorescences from diseased palms, showing the necrosis of the flower spikes

FIG. 2. Newly-fallen nuts from diseased trees, showing the necroses at the basal ends

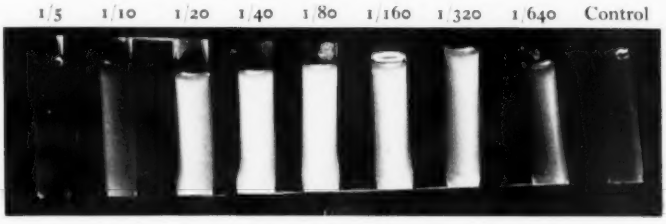


FIG. 1. Photograph of precipitin test with diseased-sap antiserum against diseased-plant sap. More than two weeks after preparation of antiserum

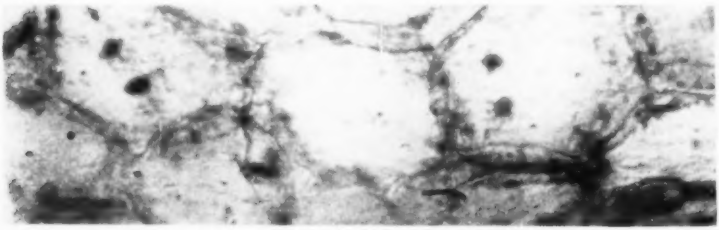


FIG. 2. Epidermal strip from diseased palm showing two binucleate cells

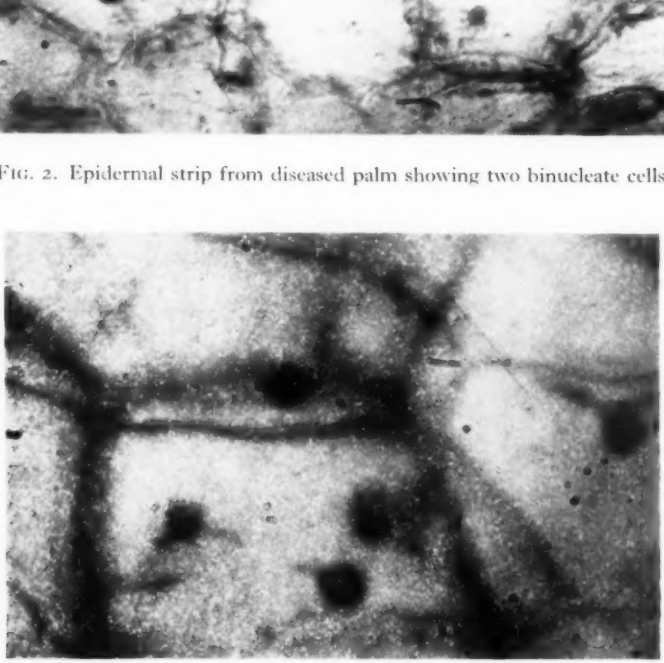


FIG. 3. Epidermal strip from diseased palm showing one cell with three nuclei

of serological work; and failure to induce recovery by treatments likely to have been effective with most non-virus pathogens.

Direct control seems impracticable, and the use of resistant varieties (one such being already available) seems to offer the best chance of re-establishment of devastated plantations.

Acknowledgements.—Our thanks are due to the Director and members of the Department of Agriculture for their courtesy and co-operation in these investigations and for giving us access to their official files: to those landowners who allowed us to use their plantations, and to Dr. F. T. Ranson, F.R.C.S., who kindly undertook to inject and to bleed the rabbits. Leaf-samples of healthy palms were kindly supplied by the late Professor R. E. D. Baker, from Trinidad, and by Dr. Jagoe, from Malaya.

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(*Received 6 June 1955*)

FROND-DROP. A NOTE ON AN ABNORMAL CONDITION OF COCONUT PALMS IN JAMAICA

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With Plates 14 and 15

A CONDITION of coconut palms characterized by premature drooping of the fronds was described in Trinidad by Briton-Jones [1], who considered it to be genetical in origin. Martyn [2] wrote of a similar condition in Jamaica, and agreed with Briton-Jones as to its cause. Both these workers were apparently influenced by Sampson [3] who described as genetically undesirable certain types of palms which have thin petioles with long leaves and peduncles. When such palms set a heavy crop the weight of nut clusters forces the leaves down, and, as a result, the unsupported peduncles tend to hang vertically, and nuts are often shed.

We have observed that a superficially similar condition is comparatively widespread in Jamaica. It seems to be more serious than the descriptions given by Martyn and by Briton-Jones would imply, and has more the character of a pathological disease than an inherent condition. It is not known whether these workers in fact described the type of palm referred to by Sampson, or the disease which is the subject of this note: the latter, however, seems to be the more probable.

Palms of all ages are affected: but in young ones the symptoms are more definite, and the progress of the disease more rapid. For instance, one young tree which was first observed when exhibiting early symptoms was in an advanced stage of the disease 4 months later, and after 8 months was moribund. The first sign of abnormality is a collapse of the older and lower fronds, usually while these are still green, and progressively younger fronds continue to collapse until only a central tuft of abnormally short and pale fronds remains (Plate 14, Fig. 1 and Plate 15, Fig. 1). The immediate cause of the drooping is a buckling at the base of the petiole, but, in addition, the midrib often breaks across at some distance from the trunk. The bud-rot which accompanies many other coconut-palm diseases is not directly involved in this condition, but the growing point does finally die, leaving the trunk swathed with the drooping dead brown fronds (Plate 14, Fig. 2). Briton-Jones reports that recovery can occur from the condition described by him, but we do not know of any instances of recovery from the frond-drop condition described here.

The drooping of the fronds seems to result partly from an abnormal weakness in the mechanical elements of the leaf, and partly from a weakness of the fibrous stipules which, in normal plants, contribute to the great strength of the attachment of the frond to the trunk. A frond can be pulled by hand from the trunk of an affected palm with little effort, which would be impossible with a healthy one.

In recently affected palms the older and lower nut clusters seem

[Empire Journ. of Exper. Agric., Vol. 23, No. 91–92, 1955]

normal, except that the peduncles appear weaker than usual, and are sometimes pendent, even when they bear very few nuts (Plate 14, Figs. 1 and 3). Later-formed inflorescences tend to be progressively smaller and to set fewer nuts, which are themselves often abnormally small, sometimes elongated, or otherwise distorted (Plate 15, Fig. 2c). The reduction in size of inflorescence becomes more marked the longer the tree is affected, until, finally, fully mature ones can be found which are sometimes reduced to less than 12 inches, instead of the usual length of up to 3 feet (Plate 15, Fig. 2). Apart from this reduction in size, however, the only external sign of abnormality at the time when the inflorescences emerge from their spathes is a tendency to be exceptionally rigid; immediately upon opening, they dry up and blacken, often without properly emerging. The discoloration of the unopened inflorescence characteristic of lethal yellowing [4] is absent, and internal examination fails to reveal either the presence of micro-organisms or any type of necrosis.

A certain amount of root dieback is normally found in healthy palms, and in those affected by frond-drop only the usual amount is present. Again, there is no evidence for any pathogenic attack on the root system.

Symptoms in mature trees, although similar to those in young ones, are not always so clear-cut (Plate 15, Fig. 1). This, however, may be in part because of the greater difficulty in observing them in very tall plants. Signs of degeneration seem to be evident for longer than in young palms, and frequently the condition is associated with an extensive dying back of the leaflets of the older fronds.

The condition can be seen in trees growing in rich alluvial soil; on hill-sides; and in well-drained pasture lands. Palms are affected equally in wet and in dry situations, and in soils of varying degrees of fertility. There is thus no evidence that any particular edaphic factor is responsible. No parasitic fungus or bacterium seems to be associated with the condition, and there are no obvious necroses present in any part of the tree. Binucleate cells are, however, common in the leaves of affected plants.

Many of the above observations cannot be reconciled with any genetical hypothesis, but they are, on the contrary, compatible with a pathogenic one. The fact that the frond symptoms may appear on young palms which have not come into bearing is sufficient evidence that the drooping is not caused by the weight of nut clusters. Further, young and vigorous palms, with a record of normal growth and heavy cropping for some years, can suddenly develop these abnormalities in fronds, flowers, and fruits, and die prematurely.

So far as has been observed, the epidemiology of the disease is more reminiscent of a pathological than of a genetical condition. In mature plantations compact outbreaks can be seen which are readily explicable on the basis of outward spread from individual foci. The rate of spread in young stands is sometimes very rapid. For example, the owner has reported that in one plantation of outstandingly vigorous and high-yielding young trees of about 9 years of age he first noticed the disease some 5 years ago. It has since spread to such an extent that few trees

remain unaffected, and many are dead. Mature palms on the periphery of this plantation also show symptoms, but do not seem to be dying at the same rate. Another plantation of young palms has been established in an area where, for many years, mature plants have been reported to exhibit signs of debility. Frond-drop symptoms can be seen in many of these mature trees (Plate 15, Fig. 1), and a considerable number of dead trees are scattered over the area. This young plantation, although only just of bearing age, contains a very high proportion of affected palms, and the diseased inflorescences shown in Plate 15, Fig. 2, were collected there.

There seem to be many points of similarity between frond-drop and the Kadang-kadang disease of the Philippines as described by De Leon and Bignornia [5], except that yellowing and mottling are said to be characteristic of the latter; this disease is suspected to be caused by an insect-transmitted virus. Although no positive evidence can be advanced, some of the features of frond-drop suggest that it, also, might be the result of virus infection. Among other signs, the presence of binucleate cells in the leaves of affected plants tends to strengthen this possibility, since this abnormality has been associated, so far, only with known virus infections [6], [7], [8].

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(*Received 6 June 1955*)

FIG. 1. Early stage of Frond-drop in young palm. Showing drooping green fronds, and reduced crop.

FIG. 2. Final stage of disease in a 9-year-old palm.

FIG. 3. Affected young palm showing pendent nut clusters, failure to set fruit on the younger inflorescences, and hanging fronds.

FIG. 1. Mature palms with symptoms of Frond-drop. Note the central tuft of abnormally small fronds in the central tree in the foreground. Those on each side show symptoms.

FIG. 2. A and B are spathes from young frond-drop palms. The inflorescences have not properly emerged from either. Both are dried, blackened, and abnormally small.

C illustrates gross distortion of a fully formed and mature nut (the only one to set on the inflorescence) on an affected palm.

D is the upper half of an unopened spathe from a healthy palm for comparison with A and B.

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